Bond University

DOCTORAL THESIS

Effects of Surfing on Bone.

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Effects of Surfing on Bone

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Secondary Supervisors: Professor Rodney Pope, Professor Belinda Beck, Associate Professor Mike Climstein

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Abstract

Surfing is one of the fastest growing sports in the world, with a number of participants estimated at nearly 40 million worldwide. In Australia, surfing became popular in the 1950s, and many surfers are now middle-aged or older. As such, bone-related health issues have become a major concern. Specifically, skeletal bone health and the bone health of the external auditory canal (EAC) which are the two main focus areas of this thesis.

It is well-known that aging is associated with loss of bone mass, directly related to conditions clinically known as osteopenia and osteoporosis. Therefore, prevention is paramount. Exercise is widely accepted as a non-pharmacological strategy to reduce the age-related bone deterioration; however, not all types of exercise are able to contribute to a positive benefit. The first main focus area of this program of research (Chapters 3 to 5) addresses the relationships between skeletal bone health and surfing, including water-based exercise in general. Findings of our studies suggest that male surfers and post-menopausal women engaged in water-based exercise can potentially decrease the rate of bone deterioration associated with age.

The bone health of the EAC, the second main focus area of this thesis, is explored within Chapters 6 to 9. Exostosis of the EAC, popular known as surfer's ear, is a common consequence of long-term surfing. However, to date this pathology has been mainly associated with cold waters, with no studies investigating surfers exclusively exposed to warm water conditions. Furthermore, through the literature search (Chapter 2), a discrepancy was found between self-reported prevalence of the condition and the prevalence found via otoscopic examination. Our results revealed that exostosis of the auditory canal is prevalent in individuals exposed to surfing conditions, regardless of water temperature. Additionally, we found that surfers, although aware of surfer's ear, are often undiagnosed.

This program of research has demonstrated the relationships between bone health and the sport of surfing. It was found a positive association between long-term surfing and skeletal bone health, potentially preventing conditions such as osteopenia and osteoporosis. However, surfers are exposed to exostosis of the EAC, regardless of environmental conditions, and effective prevention methods should be investigated.

Keywords: Surfing, bone health, osteoporosis, auditory exostosis, otology, preventive medicine, sports and exercise medicine.

Declaration by author

This thesis is submitted to Bond University in fulfillment of the requirements of the degree of Doctor of Philosophy by Research.

I declare that the research presented within this thesis is a product of my own original ideas and work and contains no material which has previously been submitted for a degree at this university or any other institution, except where due acknowledgement has been made.

Vinícius Perez Simas

Signature: ________________________________

Declaration of author contributions

The authors listed below have all approved inclusion and publication of the manuscripts contained within this thesis. Relative contributions are provided for each study manuscript.

Manuscript	Contribution
Simas V, Furness J, Hing W, Pope R, Walsh J, Climstein M. Ear discomfort in a competitive surfer. *Aust Fam Physician*. 2016 Sep;45(9):644-6.	**VS 80%**, JF 3% WH 5%, RP 5%, JW 2%, MC 5%
Simas V, Hing W, Pope R, Climstein M. Effects of water-based exercise on bone health of middle-aged and older adults: a systematic review and meta-analysis. *Open Access J Sports Med*. 2017 Mar 27; 8:39-60. doi: 10.2147/OAJSM.S129182.	**VS 85%**, WH 5%, RP 5%, MC 5%
Shiel F, Persson C, **Simas V**, Furness J, Climstein M, Schram B. Investigating the level of agreement of two positioning protocols when using dual energy X-ray absorptiometry in the assessment of body composition. *PeerJ*. 2017 Oct 16; 5:e3880. i: 10.7717/peerj.3880.	FS 30%, CP 30%, **VS 25%**, JF 5%, MC 5%, BS 5%
Shiel F, Persson C, **Simas V**, Furness J, Climstein M, Pope R, Schram B. Reliability and Precision of the Nana Protocol to Assess Body Composition Using Dual Energy X-Ray Absorptiometry. *Int J Sport Nutr Exerc Metab*. 2018 Jan 1;28(1):19-25. doi: 10.1123/ijsnem.2017-0174.	FS 30%, CP 30%, **VS 20%**, JF 5%, MC 5%, RP 5%, BS 5%
Shiel F, Persson C, Furness J, **Simas V**, Pope R, Climstein M, Hing W, Schram B. Dual energy X-ray absorptiometry positioning protocols in assessing body composition: A systematic review of the literature. *J Sci Med Sport*. 2018 Oct;21(10):1038-1044. doi: 10.1016/j.jsams.2018.03.005.	FS 30%, CP 30%, JF 10%, **VS 10%**, RP 5%, MC 5%, WH 5%, BS 5%

Simas V, Remnant D, Furness J, Bacon C, Moran R, Hing W, Climstein M. Lifetime Prevalence of Exostoses in New Zealand Surfers. *J Prim Health Care*. 2019 Apr;11(1):47-53. doi: 10.1071/HC18097.	**VS 70%**, DR 5%, JF 5%, CB 5%, RM 5%, WH 5%, MC 5%
Simas V, Hing W, Rathbone E, Pope R, Beck B, Climstein M. Bone health of middle-aged and older surfers. *Open Access J Sports Med.* 2019 Sep 6;10:123-132. doi: 10.2147/OAJSM.S209043. eCollection 2019.	**VS 80%**, WH 5% ER 2%, RP 5%, BB 3%, MC 5%
Simas V, Hing W, Furness J, Walsh J, Climstein M. The Prevalence and Severity of External Auditory Exostosis in Young to Quadragenarian-Aged Warm-Water Surfers: A Preliminary Study. *Sports (Basel).* 2020 Feb 4;8(2). pii: E17. doi: 10.3390/sports8020017.	**VS 80%**, WH 5%, JF 5%, JW 5%, MC 5%
Simas V, Hing W, Rathbone E, Pope R, Climstein M. Auditory exostosis in Australian warm water surfers: prevalence and severity. (Under review).	**VS 80%**, WH 5%, ER 5%, RP 5%, MC 5%
Simas V, Hing W, Pope R, Climstein M. Australian surfers' awareness of 'surfer's ear'. (Accepted, *BMJ Open Sport & Exercise Medicine*).	**VS 85%**, WH 5%, RP 5%, MC 5%

Research outputs arising from this thesis

Peer-reviewed publications

- **Simas V**, Furness J, Hing W, Pope R, Walsh J, Climstein M. Ear discomfort in a competitive surfer. *Aust Fam Physician*. 2016 Sep;45(9):644-6
- **Simas V**, Hing W, Pope R, Climstein M. Effects of water-based exercise on bone health of middle-aged and older adults: a systematic review and meta-analysis. *Open Access J Sports Med*. 2017 Mar 27;8:39-60. doi: 10.2147/OAJSM.S129182.
- Shiel F, Persson C, **Simas V**, Furness J, Climstein M, Schram B. Investigating the level of agreement of two positioning protocols when using dual energy X-ray absorptiometry in the assessment of body composition. *PeerJ*. 2017 Oct 16;5:e3880. doi: 10.7717/peerj.3880.
- Shiel F, Persson C, **Simas V**, Furness J, Climstein M, Pope R, Schram B. Reliability and Precision of the Nana Protocol to Assess Body Composition Using Dual Energy X-Ray Absorptiometry. *Int J Sport Nutr Exerc Metab*. 2018 Jan 1;28(1):19-25. doi: 10.1123/ijsnem.2017-0174.
- Shiel F, Persson C, Furness J, **Simas V**, Pope R, Climstein M, Hing W, Schram B. Dual energy X-ray absorptiometry positioning protocols in assessing body composition: A systematic review of the literature. *J Sci Med Sport*. 2018 Oct;21(10):1038-1044. doi: 10.1016/j.jsams.2018.03.005.
- **Simas V**, Remnant D, Furness J, Bacon C, Moran R, Hing W, Climstein M. Lifetime Prevalence of Exostoses in New Zealand Surfers. *J Prim Health Care*. 2019 Apr;11(1):47-53. doi: 10.1071/HC18097.
- **Simas V**, Hing W, Rathbone E, Pope R, Beck B, Climstein M. Bone health of middle-aged and older surfers. *Open Access J Sports Med*. 2019 Sep 6;10:123-132. doi: 10.2147/OAJSM.S209043. eCollection 2019.
- **Simas V**, Hing W, Furness J, Walsh J, Climstein M. The Prevalence and Severity of External Auditory Exostosis in Young to Quadragenarian-Aged Warm-Water Surfers: A Preliminary Study. *Sports (Basel).* 2020 Feb 4;8(2). pii: E17. doi: 10.3390/sports8020017.
- **Simas V**, Hing W, Pope R, Climstein M. Australian surfers' awareness of 'surfer's ear'. (Accepted, *BMJ Open Sport & Exercise Medicine*).

Manuscripts submitted

- **Simas V**, Hing W, Rathbone E, Pope R, Climstein M. Auditory exostosis in Australian warm water surfers: prevalence and severity. (Under review).

Ethics declaration

As this program of research involved human subjects, it was necessary to ensure that the proposed studies were approved by a properly constituted human research ethics committee, and so that they were conducted in accordance with relevant ethical standards and guidelines in order to ensure protection of the welfare and rights of participants in the research. Therefore, the Ph.D. studies were submitted to the Bond University Human Research Ethics Committee (BUHREC) and Unitec Research Ethics Committee (UREC) for approval. Applications were submitted, encompassing all of the planned Ph.D. studies.

Details of the ethics application and its approval status are presented in Table **1**.

Table 1: ETHICS application status

Committee Name	Application ID	Status
Bond University Human Research Ethics Committee (BUHREC)	15221	Approved
Unitec Research Ethics Committee (UREC)	2015-1032	Approved

Copyright declaration

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Without the inspiration, drive, and support that you have given me, I wouldn't be the person I am today. Some people don't believe in heroes, and that is because they haven't met my dad.

Aloha, Pura Vida!

Vini Simas

"*Wisdom is not a product of schooling but of the lifelong attempt to acquire it.*"

Albert Einstein (1879-1955)

Table of Contents

List of Tables

List of Figures

List of abbreviations

- EAC – external auditory canal
- BUHREC – Bond University Human Research Ethics Committee
- UREC – Unitec Research Ethics Committee
- WHO – World Health Organization
- BMD – bone mineral density
- BMC – bone mineral content
- EAC – external auditory canal
- EAE – external auditory exostosis
- PTH – parathyroid hormone
- GH – growth hormone
- IGF – insulin-like growth factor
- IL – interleukin
- TGF – transforming growth factor
- BMP – bone morphogenetic proteins
- FGF – fibroblast growth factors
- PDGF – platelet derived growth factor
- G-CSF – granulocyte colony-stimulating factor
- GM-CSF – granulocyte macrophage colony-stimulating factor
- TNF – tumor necrosis factor
- BMU – bone multicellular unit
- DXA – dual energy x-ray absorptiometry
- CRPS – complex regional pain syndrome
- SD – standard deviation
- AusICUROS – Australian Study of Cost and Utilities Related to Osteoporotic Fractures
- HIV – human immunodeficiency virus
- FRC – fracture risk calculator
- BMI – body mass index
- aBMD – aerial BMD
- vBMD – volumetric BMD
- g – grams

- cm – centimeter
- mSv – millisievert
- CT – computed tomography
- ROI – region of interest
- UD – ultra-distal
- QA – quality assurance
- QC – quality control
- QUS – quantitative ultrasound
- SOS – speed of sound
- BUA – broadband ultrasound attenuation
- 3D – three-dimensional
- QCT – quantitative computed tomography
- pQCT – peripheral QCT
- HR-QCT – high-resolution QCT
- MRI – magnetic resonance
- P-DXA – peripheral DXA
- DXR – digital x-ray radiogrammetry
- CBC – complete blood count
- TSH – thyroid stimulating hormone
- SEP – serum electrophoresis
- Ig – immunoglobulin
- FSH – follicle-stimulating hormone
- LH – luteinizing hormone
- UPEP – urine protein electrophoresis
- CTx – carboxy-terminal telopeptide cross-linked type 1 collagen
- NTx – collagen amino-terminal telopeptide
- OC – osteocalcin
- BALP – bone-specific alkaline phosphatase
- P1NP – procollagen type 1 amino-terminal propeptide
- mg – milligrams
- IU – international units
- nmol – nanomole
- L – liter
- UV – ultraviolet

- mL – milliliter
- ACSM – American College of Sports Medicine
- RM – repetitium maximum
- RCT – randomized controlled trial
- HRT – hormone replacement therapy
- SERMS – selective estrogen receptor modulators
- VTE – venous thromboembolism
- CI – confidence interval
- SLSA – Surf Life Saving Australia
- MVC – maximal isometric voluntary contraction force
- OR – odds ratio
- USA – United States of America
- WBE – water-based exercise
- LE – land exercise
- PRISMA – preferred reporting items for systematic reviews
- PROSPERO - prospectively registered systematic reviews in health and social care
- MD – mean difference
- SMD – standardized mean difference
- QE – quasi-experiment
- LS – lumbar spine
- FN – femoral neck
- GT – great trochanter
- WT – Ward's triangle
- TF – total femur
- GS – grip strength
- QS – quadriceps strength
- BRPT – bend reach performance test
- SBTVC – static balance test with visual control
- BBS – Berg balance scale
- NHANES – National Health and Nutrition Examination Survey
- LM – lean mass
- SBC – segmental body composition
- ISCD – International Society for Clinical Densitometry

- ANZBMS – Australian and New Zealand Bone Mineral Society
- CAT – critical appraisal tool
- ICC – intraclass correlation coefficient
- CV – coefficient of variation
- CV% - CV percentage
- FM – fat mass
- SRD – smallest real difference
- SRD% – SRD percentage
- SEM – smallest error measurement
- SEM% – SEM percentage
- BC – body composition
- SWE – smallest worthwhile effect
- WBRU – Water Based Research Unit
- BIHS – Bond Institute of Health and Sport
- BPAQ – bone-specific physical activity questionnaire
- cBPAQ – current BPAQ
- pBPAQ – past BPAQ
- tBPAQ – total BPAQ
- WBHI – weight-bearing/high intensity
- NWBLI – non-weight-bearing/low intensity
- GC – Gold Coast
- RDI – recommended daily intake
- %RDI – percentage of RDI
- GRF – ground reaction force
- EAE – external auditory exostosis
- OE – otitis externa
- SSE – south southeast
- ^{o}C – degrees Celsius
- NZ – New Zealand

Thesis structure

At the time of the commencement of this thesis, there appeared to only be one published study that addressed skeletal bone health of surfers, with limitations that affected extrapolation of its results. Additionally, external auditory exostosis (EAE) was perceived to be mainly associated with cold-water surfing, with differences found between self-reported prevalence and the prevalence found via otoscopic examination.

Therefore, this thesis sought to address both topics, which are related to the bone health of surfers. The thesis is arranged into ten chapters, centered on two major areas (Figure 1): skeletal bone health and bone health of the external auditory canal (EAC).

Chapter 1 is the introductory section, providing the background to this thesis together with its aims and hypotheses. In Chapter 2, a review of the literature related to bone health and surfing is detailed, highlighting the major gaps in prior research.

The first major area, skeletal bone health, is then approached through Chapters 3, 4, and 5. In Chapter 3, a systematic literature review with meta-analyses investigated the effects of water-based exercise on the bone-health of middle-aged and older adults. Chapter 4 examines the reliability and precision of the dual-energy x-ray absorptiometry scan (DXA) and its positioning protocols, to determine body composition (BC) and bone mineral density (BMD). Then, Chapter 5 investigates the bone health of middle-aged and older adult surfers, comparing the results with those for age- and sex-matched active individuals who were non-surfers.

The second major area of this thesis, the bone health of the EAC, is explored through Chapters 6, 7, 8, and 9. Chapter 6 presents a case study of EAE, commonly known as 'surfer's ear', where the condition is detailed through the format of questions and answers. In Chapter 7, the prevalence and severity of EAE in warm water surfers is examined. Chapter 8 investigates the prevalence of the condition in cold water surfers, via an online survey. Chapter 9 explores the awareness among Australian surfers of EAE, in order to understand the discrepancy between self-reported prevalence of EAE and the prevalence found via otoscopic examination.

Finally, Chapter 10 provides discussion of the main findings, acknowledging the limitations of the thesis, and proposing future research in the field.

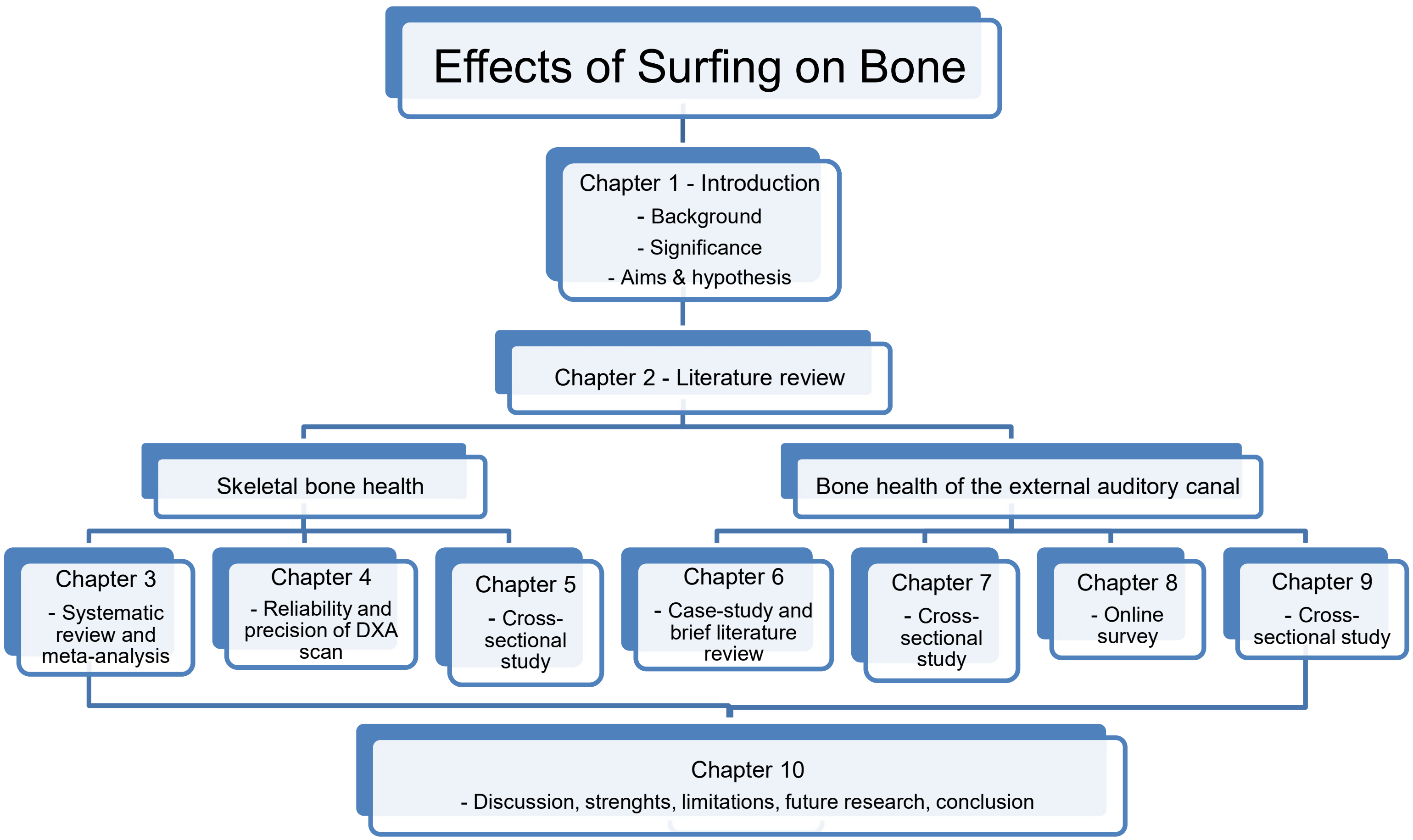

Figure 1: Thesis overview

Chapter 1: Introduction

Background

Australia is experiencing a worldwide phenomenon of growing life expectancy, as well as a rise in the number of people over 60 years of age.[1] This age group is considered the fastest growing in the world and is expected to reach approximately 2 billion by 2050.[2-4] Ageing is frequently associated with bone loss, and, as a serious consequence, the incidence of fractures has emerged as a major public health concern.

Loss of bone mass and micro-architectural deterioration of bone tissue are directly related to decrease in bone strength and a higher fracture risk, and ultimately lead to conditions clinically known as osteopenia and osteoporosis.[5,6] Osteopenia, a pre-osteoporotic condition, is defined by the World Health Organization (WHO) as a bone mineral density (BMD) at the hip and/or the spine equal to one standard deviation below (-1.0) to two and one-half standard deviations below (-2.5) the BMD values of a reference group.[7] Osteoporosis is a systemic skeletal disease, defined by WHO as a BMD at the hip and/or spine equal to or more than two and one-half standard deviations below (-2.5) the BMD values of a reference group.[7] Osteoporosis can be defined as either primary, when the bone disorder is related to aging, without other underlying origin; or secondary, when there is a direct cause, such as chronic diseases or certain types of prescribed medications.

Osteoporotic fractures have particular importance in public health and are considered one of the most common causes of disability, as well as a major contributor to medical care costs around the world.[8] In Australia, it is estimated that osteoporosis and osteopenia affect approximately 7.5 million people,[9,10] with the estimated total number of fractures over the next 10 years predicted to be in excess of 1.6 million (new fractures and re-fractures) and estimated total direct and indirect costs to government, community and individuals of AU$33.6 billion in this period.[11]

The most common sites of osteoporotic fractures are the hips, spine and forearm. Approximately 30% of older adults who have experienced a hip fracture do not reach their pre-fracture level of functioning within one year post-fracture, and the individuals who do recover tend to take approximately six months to return to their pre-fracture levels of functioning.[12] In the year following a hip fracture, there is a two-fold increased mortality.[13] Vertebral fractures are often asymptomatic, therefore escaping clinical diagnosis; however, when compared to other types of fractures, they are associated with higher comorbidity, higher incidence of hospitalization, and longer hospital stays.[14] In addition, they have been strongly associated with subsequent fractures and mortality.[14,15] Fractures of the distal radius are more common in women and are considered a sensitive marker for subsequent hip fracture and mortality.[16]

The current available pharmacological treatment for osteoporosis, besides being costly, may have several negative side-effects.[17] It is, therefore, important to focus upon non-pharmacological approaches in the prevention of bone deterioration. Adequate levels of calcium and vitamin D are well established as key factors for bone health. A physically active lifestyle is also recognized as a prevention strategy, with a vast variety of exercise modes being evaluated.

However, not all types of exercise are able to promote positive effects on bones.[18] Traditionally, only physical activities resulting in high-impact mechanical loading have been associated with a positive effect on bone tissue,[19,20] with some sports being associated with either no effects or with increased risk of fractures due to bone loss. For instance, Pereira Silva et al.[21] reported that scuba divers had a femoral neck BMD 4.6% lower than that of a non-diving control group. Exercise in the water environment, often called water-based exercise, is known to involve reduced the weight bearing, which may lead to a negative effect on bones. Nonetheless, the literature remains inconsistent regarding the effects of water-based exercise on bone health. Velez et al.[22] reported that mature aged males who restricted their physical activity to only swimming had a 10% higher prevalence of osteoporosis as compared to sedentary age- and sex-matched controls. On the other hand, Balsamo et al.[23] conducted a cross-sectional study and concluded that aquatic exercise might be a viable non-pharmacological strategy to prevent bone loss in postmenopausal women.

There is a range of factors that influence bone density. It is estimated that around 60 to 80% of the variation in bone strength is determined by genetics,[24-27] and the remaining 20-40% can be attributed to lifestyle and environmental factors,[28] such as nutrition, alcohol intake, smoking and skeletal loading. Despite the importance of genetic background, it has been found that bones are capable of positively adapting their mass, microstructure and strength when repeatedly and routinely exposed to external stimulus.[29] Additionally, BMD is highly associated with lean body mass.[30-32] These findings support the idea that changes in muscle quality (ie, mass, size and strength) are directly related to changes in bone quality (ie, mass, structure and strength), as suggested by the functional "muscle-bone" unit concept.[33,34] Previous research has demonstrated that muscle contractions increase loads on bone, producing stress and strain reactions in its tissue,[35-37] and also that dynamic loading has more effect on bone tissue than static loading.[38] In addition to this, it has been proposed that, regarding bone health, the characteristics of the proposed exercise, which includes its dynamic component, play a fundamental role.[39-43]

Surfing is a popular recreational activity and competitive sport. It is also one of the fastest growing sports in the world, with participants estimated in 2012 at 37 million worldwide,[44] a statistic which has doubled if compared to the 18 million surfers estimated in 2002.[45] In Australia, number of surfers is estimated at 2.7 million.[46] Despite the remarkable growth of this activity, scientific research has been poorly mirrored in surfing when compared to most other mainstream sports.[47] The popularity of surfing started to grow in Australia in the 1950s and 1960s; therefore, there are many surfers who are now over 50 years of age, and consequently susceptible to bone loss and increased risk of fractures.[14,48] However, based on current knowledge, it is not possible to make recommendations regarding the bone health of participants in this sport. Surfing is recognized as a quasi-weight bearing (ie, having a partial load component) aquatic-based physical activity (recreational and competitive), where participants spend the majority of the time in a weight-supported environment.[49,50] Time-motion analysis of recreational surfers has indicated that surfers typically spend only three minutes standing up on the board (ie, surfing) in a 60-minute surf session.[49] This short period of standing would provide bones little stimulus for remodeling. It could, therefore, be expected that participants in this aquatic activity may have an imbalance between osteoclastic (bone resorption) and osteoblastic (bone remodeling) activity, resulting in degradation of BMD and consequently exposing surfers to premature development of osteoporosis and increased risk of fractures. However, surfing requires a wide range of physical qualities in order to paddle-out, pass through waves, “catch” a wave, balance on the surfboard, and execute and complete surfing maneuvers. Therefore, the physical activity involved in practicing these physical skills might positively influence bone health. At present, only one study exists which has investigated bone health in surfers. It was conducted by Climstein et al.,[51] and they concluded that surfing appears to be advantageous with regard to BMD and bone mineral content (BMC). However, this study did not utilize standard clinical sites of assessment.

Although the effects of surfing on skeletal bone are currently unclear, it is well-documented that surfing is associated with a high prevalence of exostosis affecting bone in the external auditory canal (EAC), also known as surfer’s ear.[52] This condition is diagnosed via otoscopic examination to identify broad-based bony growths, defined as an irreversible outgrowth of the osseous external auditory canal.[53] External auditory exostosis (EAE) usually occurs bilaterally, with multiple lesions, and is highly correlated with the amount of time spent in the water (ie, exposure to surfing).[54] This is a potentially serious health issue, and common consequences include chronic cerumen impaction, recurrent otitis externa, pain and conductive hearing loss (deafness). The definitive treatment of exostosis is surgical removal,[55] which is reserved for severe and symptomatic cases. The feasibility of prevention remains unclear; however, the use of earplugs may help prevent its occurrence.[56] Although the physiological mechanism for the development of exostoses is not known, exposure to cold water[54,57,58] and wind[59,60] are commonly cited risk factors, and the association of both factors appears to affect the severity.[61-63]. However, inconsistency in the research literature still exists. Analyses of the prevalence of such exostoses amongst warm water (water temperatures exclusively above 19°C) surfers have never been conducted, with no reported studies assessing warm water surfers in Australia. Furthermore, discrepancies exist between self-reported prevalence of the condition and the prevalence found when examining individuals via otoscopic examination.[64,65]

There is, therefore, substantial scope for research investigating the associations between surfing and adaptations in bone tissue of the skeletal system and external auditory canal, in order to inform recommendations regarding how best to manage bone health of the participants in this popular sport.

Significance

Given that age-related bone deterioration is a major health problem, recommendations are necessary regarding ways to maintain and improve bone health of middle-aged and older adults. However, the effects of surfing on skeletal bone are unclear. Moreover, there is inconsistency in evidence regarding the effects of water-based exercise in general on bone health. In addition to this, there is scarce data on the prevalence and severity of exostosis, another important bone issue for surfers, in warm water surfers. The results of this Ph.D. are expected to inform participants in this popular sport regarding the relationship between participation in surfing and bone health, including skeletal bone health and the health of bone in the EAC.

Aims and Hypotheses

Aims

The overall aim of this Ph.D. thesis is to examine the relationships between surfing and bone health, specifically skeletal bone health and the health of the osseous external auditory canal.

The overarching research question is as follows: *What are the relationships between surfing and bone health?*

The specific objectives of the program of research are:

- To review reported effects of water-based exercise, including surfing, on bone health of middle-aged and older adults;
- To analyze the relationships between surfing and bone mineral density (BMD) of middle-aged and older male adults;
- To analyze the relationships between surfing and bone metabolism (via bone biomarkers), by analyzing osteoclastic (bone resorption) and osteoblastic (bone formation) activity;
- To analyze the prevalence and severity of external auditory exostoses (EAE) in warm-water surfers compared to cold-water surfers.
- To assess awareness of EAE and associated prevention strategies amongst Australian surfers.

Hypotheses

Key research hypotheses are as follows:

1. Surfers have the same BMD and bone metabolism when compared to age- and sex-matched active individuals who are non-surfers.
2. Surfers have the same rate of bone formation and same rate of bone resorption when compared to age and sex-matched active individuals who are non-surfers.
3. Warm-water surfers have the same prevalence of auditory exostoses when compared to cold-water surfers.
4. Australian surfers have low awareness of auditory exostoses and associated prevention strategies.

Chapter 2: Literature review

Preface

The purpose of this chapter is to review the literature on important topics related to bone health and surfing. It begins by briefly discussing population aging. In the section that follows, skeletal bone health will be outlined and detailed. It will summarily explain the bone biology, moving then to discuss the major consequence of bone deterioration (ie, osteoporosis), followed by a delineation of clinical methods for assessing bone quality. Then, non-pharmacological approaches to managing bone health will be detailed, with emphasis on physical activity and exercise. The chapter then goes on to discuss the sport of surfing, reviewing its history, analyzing its popularity, and exploring physiological aspects of the sport that are potentially relevant to bone health. The literature concerning the sport will be explored. Finally, injuries related to surfing participation will be summarised, highlighting a known negative effect of surfing participation on bone, which is exostosis of the external auditory canal.

Aging

Worldwide, the number of individuals aged 60 years and over is rapidly expanding, increasing faster when compared to other age ranges.[2,4] This can be considered a result of both a longer life expectancy (decreased death rate) and declining fertility rates.[66] In 2006, it was estimated that 688 million people were 60 years or older, and, by the year 2050, this age group is expected to increase to 2 billion, becoming larger than the age group of children under the age of 14 years.[2]

In Australia, the number of people aged 65 years and over is projected to more than double by 2055, when compared to today, with the expected number of people aged 100 years and over being 40,000.[1] Moreover, in the next 40 years, male life expectancy is projected to increase from 91.5 years today to 95.1 years, and female life expectancy from 93.6 years today to 96.6 years.[1]

Aging is a natural consequence of life, a complex, multifactorial process that involves physical, psychological and social changes. Physiological aging is a modifiable continuum, the result of a disharmony caused by extrinsic factors (stressors, eg, free radicals and lifestyle factors) and intrinsic factors (inherent mechanisms, eg, genetic predisposition); it is, therefore, an individual process.[67]

Besides being considered a great achievement of humanity, population aging demands special strategies in terms of public health.[66] It is well documented that older individuals are subjected to a general decline in physical and cognitive functions, and are more likely to have a multitude of co-morbidities. The loss of bone quality is among the most common consequences, leading to situations clinically known as osteopenia and osteoporosis, increasing the risk of fractures.

Bone Health

Bone biology

Unlike other connective tissues, bone is a specialized connective tissue, with a mineralized matrix that contains organic and inorganic components. The organic matrix, which gives bone its flexibility, makes up around 30% to 35% of bone wet weight. It is composed of 90% to 95% collagen fibers, which are predominantly type I, but also types V, VI, VIII, and XII, and a homogeneous gelatinous medium called ground substance, composed of non-collagenous protein (eg, osteocalcin) and growth factors.[68] The majority of the total bone wet weight, approximately 70%, is constituted of inorganic matrix.[68] It is composed principally of calcium and phosphate, as a chemical arrangement termed hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), responsible for the majority of bone's stiffness.[68,69] Bone matrix plays an essential role in bone homeostasis, and the amounts and distribution of both organic and inorganic components will determine bone's ability to balance its flexibility and stiffness.

The main functions of bones can be classified into three categories[70]:

1. Mechanical: serves as an anchorage for muscles, enabling movement, supports the body against gravity; and protects soft tissues and vital organs;
2. Chemical: serves as reservoir of growth factors and cytokines; and is responsible for mineral homeostasis and acid-base balance;
3. Hematological: contains hematopoietic stem cells; and is responsible for the synthesis of blood cells.

There are four categories of bones: long (eg, radius, femur), short (eg, tarsal and carpal bones), flat (eg, ribs, skull), and irregular (eg, sacrum, vertebrae).[70] In a macroscopic analysis of bone, two different types of tissue can be identified: cortical and trabecular.[69] This division is based on their porosity and unit microstructure. Both types, cortical and trabecular, have the same matrix composition, differing in terms of their architecture and function. The ratio of cortical to trabecular bone varies throughout the skeleton, being arranged to accommodate inputs of stresses and strains to the bone tissue.[69,70] For instance, the femoral shaft is a predominantly cortical site, and the lumbar spine is a predominantly trabecular site.

Cortical (or compact) bone comprises nearly 80% of the skeleton weight and is most common in the long bone shafts, or diaphysis, of the body (limbs, appendicular skeleton).[69,70] It is thick and dense, with porosity around 5% of its total volume.[70] Cortical bone is, therefore, highly resistant to bending and torsion, with a slow turnover rate, about 2 to 3% per year.[70] It provides a great compressive strength, which contributes to its mechanical and protective role, and surrounds the marrow space (medullary canal).[69] The structural subunits are arranged in osteons, with neurovascular channels known as Haversian canals, which are the transport systems for nutrients.[68,70] Cortical bone is composed of three layers: periosteal envelope (outer surface), intracortical envelope (middle layer), and endosteal envelope (inner surface).[71] The cortex becomes less dense and more porous in the aging process.[72]

Trabecular (or cancellous) bone is more porous, less dense and more elastic than cortical bone. Porosity ranges between 50 to 90%, giving the trabecular bone its sponge-like appearance.[73] It represents 80% of the bone surface, but only 20% of the skeletal mass and is more common in short bones, in long bones (epiphyseal and metaphyseal regions), and in the bones of the axial skeleton (rib cage, the spine). Matrix mass is reduced in trabecular bone and this, together with its high porosity, reduces its compressive strength.[73] However, when compared to cortical bone, trabecular bone has a higher turnover rate, playing an important role in metabolic changes and responding more rapidly to mechanical loading and unloading, and also to drugs that affect bone metabolism.[69] Therefore, cancellous bone has an increased rate of loss, which starts at an earlier stage in life.[73]

Bone is greatly vascularized, with an elevated metabolic activity, giving a dynamic characteristic to this organ.[48] It changes its shape in response to a variety of stimuli (physiological and mechanical), with these changes mediated by its cellular elements.[70] There are four groups of bone cells: osteoblasts, bone lining cells, osteocytes, and osteoclasts.[69] The replication and differentiation of osteoclast and osteoblast progenitors are modulated by circulating hormones (estrogen, glucocorticoid, parathyroid hormone, and calcitonin) and locally produced cytokines and growth factors.[69] Osteoblasts, osteoclasts and bone lining cells are located in the exterior of bone; in contrast, osteocytes are positioned in the inner parts, dispersed throughout the matrix.[69]

In order to maintain bone mechanical strength, volume and mineral homeostasis (calcium and phosphate), old bone needs to be replaced by new bone, a process known as bone remodelling.[70] This process is divided into bone formation (mediated by osteoblasts) and bone resorption (mediated by osteoclasts).[70] It is believed that bone formation is influenced by bone lining cells[74] and that osteocytes play a fundamental role in this process, acting as mechanosensors and orchestrators.[70] Osteoclasts, osteoblasts, osteocytes and bone lining cells, together with connective tissue and blood supply, form an anatomical structure called a basic multicellular unit, which is responsible for the process of bone remodeling.[75] The mechanism of bone remodeling consists of four phases: activation (recruitment and activation of osteoclast precursors), resorption (digestion of the organic matrix by osteoclasts), reversal (transition from bone resorption to bone formation) and formation (synthesis of new collagenous organic matrix and mineralization of matrix by osteoblasts).[70]

The complete process of bone remodeling lasts 120 days, with approximately 100 days spent in bone formation, and is affected by a variety of factors, classified into five groups.[48]

1. Hormones:
    - Polypeptide hormones: calcitonin, parathyroid hormone (PTH), insulin, growth hormone (GH);
    - Steroid hormones: 1,25-dihydroxyvitamin D3, cortisone, sex hormones (estrogen and androgen);
    - Thyroid hormone T3.
2. Local cytokines and signals:
    - Those synthesized by bone cells: insulin-like growth factor (IGF)-I, IGF-II, beta$_2$-microglobulin, interleukin (IL)-1, IL-6, transforming growth factor (TGF)-β, bone morphogenetic proteins (BMPs), fibroblast growth factors (FGFs) and platelet-derived growth factor (PDGF);
    - Those synthesized by bone-related tissue:
        - Cartilage-derived: IGF-I, FGFs, TGF- β;
        - Blood cell derived: granulocyte-colony-stimulating factor(G-CSF), granulocyte/macrophage-CSF (GM-CSF), IL-1, tumour necrosis factor (TNF);

- Other factors: prostaglandins, binding proteins.

3. Vitamins and minerals:
    - Vitamin D, K, C, B6 and A
4. Mechanical loading;
5. Transcriptional regulation and genes.

Bone density of the skeleton reaches its maximum at approximately 30 years of age, and this is known as "peak bone mass".[48] It is estimated that genetics is responsible for approximately 60 to 80% of bone strength,[24-27] and the remaining 20-40% can be attributed to lifestyle and environmental factors,[28] such as nutrition, alcohol intake, smoking and skeletal loading. After the age of 30, a negative bone balance sets in, with an estimated 1% of bone loss every year, independent of sex.[48] The most common risk factors affecting bone quality are[48]:

- Genetic factors;
- Fetal and neonatal factors;
- Factors during growth;
- Inadequate peak bone density;
- Nutritional and lifestyle factors (eg, sedentary lifestyle);
- Menopause and reduction of estrogen in women;
- Age and deficiency of testosterone in men;
- Reduction of 80% in adrenal steroids during aging;
- Co-morbidities.

The bone multicellular units (BMUs), described above, are necessary for maintaining the integrity of the skeleton, and exert an important role in clinical situations linked to bone loss, such as osteopenia and osteoporosis [48]. Over the years, if more bone is resorbed than is produced, a negative balance occurs, decreasing the total amount of bone [48]. This leads to poor bone health, and has three possible causes[48]:

- High resorption, due to an increase of osteoclastic activity, with no changes in osteoblastic activity;
- Low formation, due to a decrease in osteoblastic activity, with no changes in osteoclastic activity;

- Atrophic bone (or adynamic bone), due to a decrease in both osteoblastic and osteoclastic activities.

Osteoporosis

Osteoporosis (from the Greek term for “porous bones”) affects both sexes and all races, and is considered the most prevalent disease linked to human bone metabolism.[76,77] It represents a major health problem, as the world population is aging. Osteoporosis is characterized by loss of bone mass, associated with degradation and disruption of bone tissue and architecture.[5] These factors decrease bone strength, predisposing the individual to an increased risk of fracture.[5,48,76]

The first definition of osteoporosis by the World Health Organisation (WHO) was as follows: *“a systemic skeletal disorder characterized by a low bone mass and microarchitectural deterioration of bone tissue, with a subsequent increase in bone fragility and susceptibility to fracture”*.[6,7,48] More recently, this definition was adapted: *“ a skeletal disorder characterized by compromised bone strength predisposing to an increased risk of fracture”*.[5] In people over 50 years of age, osteoporosis is diagnosed based on the BMD of a reference population, composed of young adults, when the value found at the lumbar spine or hip is equal to or less than 2.5 standard deviations below the mean BMD of this population.[6,7,76] A “pre-osteoporotic” condition is called osteopenia and is diagnosed based on a BMD at the hip or lumbar spine equal to 1.0 standard deviation below to 2.5 standard deviations below the mean BMD values of this same population.[6,7,76]

Table **2** shows the diagnostic criteria proposed by the WHO, based on the BMD.[76]

Table 2: World Health Organization (WHO) criteria for diagnosing osteoporosis in people over 50 years of age

Classification	BMD	T-score
Normal	Within 1 SD of the mean level for a young adult reference population	T-score at -1.0 and above
Low bone mass (osteopenia)	Between 1.0 and 2.5 SD below that of the mean level for a young adult reference population	T-score between -1.0 and -2.5
Osteoporosis	2.5 SD or more below that of the mean level for a young adult reference population	T-score at or below -2.5
Severe or established osteoporosis	2.5 SD or more below that of the mean level for a young adult reference population with fractures	T-score at or below -2.5 with one or more fractures

Abbreviations: BMD, bone mineral density; SD, standard deviation.

The WHO cut-off point of -2.5 SD for diagnosis of osteoporosis in people over 50 years of age is based upon epidemiological data derived from a population of postmenopausal Caucasian women, 50% of whom had suffered a fragile fracture. A close association was identified between the number of individuals at this cut-off point and lifetime risk of hip fractures or all fractures (hip, vertebrae, forearm, humerus, and pelvis).[48,78] This diagnostic criterion uses T-scores obtained via dual-energy X-ray absorptiometry (DXA) at the hip (femoral neck or total hip) and spine (vertebrae). However, this criterion is not applied to populations younger than 50 years.[79] Instead, it is recommended to use Z-scores when evaluating bone health at younger ages.[79]

Osteoporosis can be defined as either primary, when the bone disorder is related exclusively to aging without other underlying origin; or secondary, when there is a direct cause, such as chronic diseases or certain types of medications.[48] An extensive number of subgroups can be listed, in which the most important factors responsible for bone loss are[48]:

- According to spread (localized or generalized):
    - Inactivity (immobilization);
    - Complex regional pain syndrome (CRPS, Sudeck's disease, algodystrophy, sympathetic reflex dystrophy);
    - Transient (transitory) osteoporosis (self-limiting);
    - Gorham-Stout syndrome ("vanishing bone disease");
    - Other osteolytic syndromes (infections, tumors, trauma, and also metabolic, vascular, congenital and genetic aberrations);
    - Generalized (systemic) osteoporosis (juvenile, postmenopausal, age-related).
- According to age and sex:
    - Idiopathic juvenile osteoporosis;
    - Idiopathic osteoporosis in young adults;
    - Postmenopausal (type I), due to ovarian dysfunction, and consequently cessation of estrogen secretion, affecting females aged 51 to 75 years;
    - Age-related (involutional or type II) osteoporosis, due to a negative imbalance in the remodeling process, as discussed above.
- According to extent (degree of severity):
    - Normal bone: T-score value higher than 1 standard deviation (SD) below the reference group;
    - Low bone mass (osteopenia): T-score value more than 1 SD below the reference group, but less than 2.5 SD below this value;
    - Osteoporosis (preclinical osteoporosis): T-score value 2.5 SD or more below the reference group;
    - Severe (manifest, established) osteoporosis: T-score value 2.5 SD or more below the reference group in the presence of one or more fragility fractures.
- According to histology:

- This definition is based on biopsies conducted at the iliac crest, to analyze the trabecular bone volume, and compares this value to the volume observed in normal adults, which ranges between 20 to 25 percent by volume of the biopsy section. Values below 16% represent abnormal trabeculae.

It is important to note that testosterone deficiency in men leads to a negative imbalance in bone metabolism, increasing resorption, which generally occurs from 50 to 60 years onwards.[48]

A number of conditions, diseases and medications can cause or contribute to osteoporosis and fractures, and are listed in Figure 2.[76]

Lifestyle factors		
Alcohol abuse	Excessive thinness	Excess vitamin A
Frequent falling	High salt intake	Immobilization
Inadequate physical activity	Low calcium intake	Smoking (active or passive)
Vitamin D insufficiency		
Genetic diseases		
Cystic fibrosis	Ehlers-Danlos	Gaucher's disease
Glycogen storage diseases	Hemochromatosis	Homocystinuria
Hypophosphatasia	Marfan syndrome	Menkes steely hair syndrome
Osteogenesis imperfecta	Parental history of hip fracture	Porphyria
Riley-Day syndrome		
Hypogonadal states		
Androgen insensitivity	Anorexia nervosa	Athletic amenorrhea
Hyperprolactinemia	Panhypopituitarism	Premature menopause (<40 years)
Turner's and Klinefelter's syndromes		
Endocrine disorders		
Central obesity	Cushing's syndrome	Diabetes mellitus (types 1 and 2)
Hyperparathyroidism	Thyrotoxicosis	
Gastrointestinal disorders		
Celiac disease	Gastric bypass	Gastrointestinal surgery
Inflammatory bowel disease	Malabsorption	Pancreatic disease
Primary biliary cirrhosis		
Hematologic disorders		
Hemophilia	Leukemia and lymphomas	Monoclonal gammopathies
Multiple myeloma	Sickle cell disease	Systemic mastocytosis
Thalassemia		
Rheumatologic and autoimmune diseases		
Ankylosing spondylitis	Other rheumatic and autoimmune diseases	
Rheumatoid arthritis	Systemic lupus	
Neurological and musculoskeletal risk factors		
Epilepsy	Multiple sclerosis	Muscular dystrophy
Parkinson's disease	Spinal cord injury	Stroke
Miscellaneous conditions and diseases		
AIDS/HIV	Amyloidosis	Chronic metabolic acidosis
Chronic obstructive lung disease	Congestive heart failure	Depression
End-stage renal disease	Hypercalciuria	Idiopathic scoliosis
Post-transplant bone disease	Sarcoidosis	Weight loss
Medications		
Aluminum (in antacids)	Anticoagulants (heparin)	Anticonvulsants
Aromatase inhibitors	Barbiturates	Cancer chemotherapeutic drugs
Depo-medroxyprogesterone (premenopausal contraception)	Glucocorticoids (≥5 mg/day prednisone or equivalent for ≥3 months)	GnRH (gonadotropin-releasing hormone) agonists
Lithium cyclosporine A and tacrolimus	Methotrexate	Parental nutrition
Proton pump inhibitors	Selective serotonin reuptake inhibitors	
Tamoxifen® (premenopausal use)	Thiazolidinediones (such as Actos® and Avandia®)	Thyroid hormones (in excess)

Figure 2: Conditions, diseases, and medications that cause or contribute to osteoporosis and fracture
Source: Cosman F, de Beur SJ, LeBoff MS, et al. Clinician's Guide to Prevention and Treatment of Osteoporosis. Osteoporosis Int. 2014;25(10):2359-2381[76].
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Osteoporotic Fractures

The importance of identifying loss of bone quality (ie, identifying osteopenia and osteoporosis) is to prevent the major consequence of bone fragility, which is an increased risk of fractures. Bone fracture is characterized by discontinuity in the bone tissue.[48] When the fracture is related to a situation considered to involve a minimal impact, such as fall from a standing height, it is referred to as "osteoporotic fracture", "fragility fracture", "pathologic fracture" or "low trauma fracture".[48] Osteoporotic fractures are considered important causes of disability worldwide, and significantly contribute to medical care costs.[8] Therefore, they have particular importance in public health. It is estimated that in the population over 50 years of age, approximately 50% of women and 22% of men will have a fracture related to poor bone health.[14] However, the consequences of this type of fracture may be more devastated in men. This is exemplified by the fact that the chance of dying due to a hip fracture is doubled in men, when compared to women.[80] The common sites of fractures are the hip (proximal femur), spine (vertebrae), and wrist (distal forearm).[14]

Hip fractures usually happen as a consequence of the slow and progressive loss of bone, both cortical and trabecular.[48] Approximately 30% of older adults who have experienced a hip fracture do not reach their pre-fracture level of functioning within a year post-fracture, and the individuals who do recover tend to take approximately six months to return to their pre-fracture levels of functioning.[12] In addition to this, in the year following a fracture, there is a two-fold increase in mortality.[13] DXA measurements of the hip are highly correlated to hip fractures.[48]

Vertebral fractures are often asymptomatic, therefore escaping clinical diagnosis; however, when compared to other types of fractures, they are associated with higher co-morbidity, higher incidence of hospitalization, and longer hospital stays.[14] In addition, they have been strongly associated with subsequent fractures and mortality.[14,15] The lifetime risk of vertebral fractures is 8.6% for men aged 45 years and older, and 15.4% for women.[14]

Distal radius fractures (occurring at the wrist), are also known as Colle's or Smith's fractures, and are more prevalent in women aged 45 to 65 years.[48]

The most common mechanism of these fractures is direct trauma.[48] They occur in men and women at a younger age when compared to hip or vertebral fracture.[81] Although fractures of the distal radius are considered to cause the least morbidity of all fragility fractures, they have been associated with a high prevalence (28%) of algodystrophy,[81] which is a clinical syndrome characterized by intense pain, vasomotor and trophic changes. This condition can lead to functional disability for several months or even years. In addition, these fractures are considered an important predictor of subsequent fractures and mortality.[16]

In Australia, it is estimated that osteoporosis and osteopenia affect approximately 7.5 million people, with one fragility fracture occurring every 3.6 minutes, which amounts to almost 400 per day.[9,10,82] The direct annual cost of osteoporotic fractures in 2012 was equivalent to approximately 1% of Australia's total health expenditure.[82] The total direct annual cost of hip fractures is AU$695 million, and AU$923 million for non-hip fractures.[11] According to the Australian Study of Cost and Utilities Related to Osteoporotic Fractures (AusICUROS), 64% of osteoporotic fractures result in admission to acute hospital care, with an average stay of more than seven days, and this represents 18% of all hospitalizations attributable to musculoskeletal disease.[11]

By 2022, it is estimated that there will be one fracture every 2.9 minutes, equating to 500 per day.[11] The estimated total number of osteoporotic new fractures and re-fractures over the next ten years is predicted to be in excess of 1.6 million, with an estimated total direct and indirect cost to the government, community, and individuals of AU$33.6 billion in this period.[11] Over this period, it is also projected that approximately 150,000 fractures could be prevented, with an annual saving ranging from AU$140 million to AU$187 million.[11]

It is therefore recommended that the risk of osteoporosis should be evaluated in men aged 50 years and older and in postmenopausal women, focusing on a preventative approach, such as BMD testing.[76] It is important to note that osteoporosis is preventable and treatable; however, the challenge lies in identifying bone loss at an early stage, prior to a pathological fracture, which is the first clinical sign of this silent disease.[76]

Clinical Evaluation of Bone Deterioration

Many of the consequences of bone deterioration can potentially be avoided if at-risk individuals are identified by early and correct diagnosis of bone loss, focusing upon appropriate preventive and therapeutic approaches. Therefore, precise and reliable information about bone quality is fundamental. The aims of clinical investigations are to[10,48,71,76]:

- Identify patients at risk (see Table 3);
- Identify clinical presentations that are associated with osteoporosis (eg, loss of height, increased dorsal kyphosis, back pain, fracture associated with minimal trauma);
- Confirm the diagnosis of osteoporosis;
- Elucidate the causes of the osteoporosis;
- Exclude secondary causes (see Table 4);
- Characterize the severity of bone loss;
- Identify the topography where the bone loss is occurring;
- Determine the risk of fractures;
- Decide the optimal treatment for the osteoporosis (non-pharmacological, pharmacological);
- Establish baseline parameters, in order to monitor response to the proposed treatment.

Table 3: Risk factors for osteoporosis

Non-modifiable	Modifiable
• Increasing age (over 70 years) • Fracture history (previous spinal or minimal trauma fracture) • Ethnic group (Caucasian and Oriental) • Female gender • Premature menopause (<45 years) • Low or high body mass index (BMI <21 kg/m^2 or BMI >30 kg/m^2) • Height loss (3cm or more) • History of kyphosis • History of recurrent falls • Family history of osteoporosis in first degree relative	• Low calcium intake • Low vitamin D levels • Excessive alcohol intake • Cigarette smoking • Sedentary lifestyle • Excessive caffeine intake

Abbreviation: BMI, body mass index.

Table 4: Common causes of secondary osteoporosis

Endocrine	• Cushing's syndrome • Hypogonadism • Thyrotoxicosis • Hyperparathyroidism • Hyperthyroidism • Thyroxine excess
Medications	• Glucocorticoids (longer than 3 months) • Heparin • Anticonvulsants • Antidepressants • Immunosuppressants • Aromatase inhibitors • Gonadotropin-releasing agonists
Chronic diseases	• Chronic kidney disease • Chronic liver disease • Malabsorption (eg, coeliac disease, post-gastrectomy) • Chronic inflammatory polyarthropathies (eg, rheumatoid arthritis) • Inflammatory bowel disease • HIV • Diabetes mellitus (type 1 and 2)
Others	• Nutritional • Multiple myeloma and malignancy • Monoclonal gammopathy • Transplant (organ or bone marrow) • Osteogenesis imperfecta

Abbreviation: HIV, human immunodeficiency virus.

Fracture risk calculators

Fracture risk calculators (FRCs) are web-based tools that incorporate a number of clinical risk factors to evaluate the risk of fracture over the following years.[10] Different calculators will provide different estimates; however, the recommendation of one calculator over another is not possible, due to lack of research.[10] Furthermore, a recent systematic review of the performance of these tools for predicting absolute future fracture risk in populations other than their development cohorts found that relatively few studies have been performed to date to externally validate these calculators.[83] This study highlighted that conclusive evidence is lacking with respect to the external validity of available fracture risk calculators for predicting future fracture risk in different populations in which they may be used. Nayak et al.[83] concluded that further high-quality studies to assess the calibration of risk assessment instruments in populations in which they may be used are needed before the widespread use of individual risk assessment instruments can be recommended.

Dual energy x-ray absorptiometry (DXA)

The early diagnosis of osteoporosis, before the occurrence of fractures, is established by measuring the BMD at the hip and spine.[76,84] DXA is considered the most completely developed, reliable and popular bone densitometric technique, and is the preferred clinical technique to measure BMD, mainly because of its relatively high resolution and reliability, rapid acquisition and minimal radiation.[76,84,85] Figure 3 shows a DXA scanner (General Electric, GE, Lunar Prodigy, Madison, WI, USA).

Figure 3: DXA device (General Electric, GE, Lunar Prodigy, Madison, WI, USA)

DXA provides an estimate of areal BMD (aBMD), expressed in absolute terms of grams of mineral per square centimeter scanned (g/cm^2) and relative to population norms, using either or both the Z-score or T-score. These scores are calculated as the difference between the patient's BMD and the mean BMD of a reference population,[76,85] as follows:

- The Z-score is the number of standard deviations (SD) the individual's BMD is located below (minus) or above (plus) the mean BMD value for people of the same age and sex (age- and sex-matched control). A Z-score less than -2.0 SD may indicate an underlying pathological process, requiring further investigation for secondary causes of low BMD (secondary osteoporosis). A Z-score greater than 2.0 SD may indicate high BMD syndromes, also requiring further investigation. The Z-score is used in patients younger than 50 years, including pediatric and adolescents patients.
- The T-score is the number of SD the individual's BMD is located below or above the mean value of BMD for young (20 year old) adults of the same sex, and is used in the WHO criteria to classify

osteopenia or osteoporosis. The T-score is only used for patients over 50 years of age.

DXA-derived BMD also predicts fracture risk, and can be used to monitor patients' bone health.[85] Even though there is little difference between skeletal sites in utility for the overall prediction of any fracture, femoral neck BMD is the best overall predictor of fracture risk.[48,76] Each SD reduction in femoral neck BMD increases the age-adjusted risk of hip fracture by a factor of 2.6 and the risk of any minimal trauma fracture (eg, from falling from a standing height or less) fracture by a factor of 2.0.[85] Each SD reduction in lumbar spine BMD was found to increase the relative risk of vertebral fracture by a factor of 2.3.[85] Moreover, when the bone density decreases by 10% the fracture risk for the vertebral body is doubled, and for the hip is trebled.[48]

DXA is an extremely stable X-ray source, with high photon flux.[85] It relies upon the attenuation of a photon beam from two different photon energies, allowing the differentiation between different types of tissue, according to their density.[85] For instance, bone, a high-density tissue, will absorb more photons than soft tissue, which contains low-density material and will, therefore, transmit more photons.[85] Effective doses of radiation from single applications of bone densitometry are very low compared to naturally occurring background (or ubiquitous) radiation (eg, inhalation of air, ingestion of food and water, terrestrial radiation from ground, cosmic radiation from space), and low compared with other common diagnostic radiological tests (eg, chest x-ray).[85] Table 5 compares radiation dose (expressed in millisievert, mSv) received from DXA to that received from other common diagnostic exams and to the number of days of exposure to natural background radiation that equates to the dose each exam type delivers.[86,87]

Table 5: Radiation dose of common diagnostic exams

Exam	Radiation Dose	Comparable Natural Background Radiation
Bone Densitometry (DXA) for total body	0.01 mSv	1 day
Radiography-Chest	0.1 mSv	10 days
Radiography-Spine	1.5 mSv	6 months
Radiography-Extremity	0.001 mSv	Less than 1 day
Computed Tomography (CT)-Abdomen	10 mSv	3 years
Computed Tomography (CT)-Colonography	5 mSv	20 months
Computed Tomography (CT)-Head	2 mSv	8 months
Computed Tomography (CT)-Spine	10 mSv	3 years
Computed Tomography (CT)-Chest	8 mSv	3 years
Computed Tomography (CT)-Sinuses	0.6 mSv	2 months
Coronary Artery CT	6 mSv	2 years

The traditional clinical sites at which BMD is measured in DXA analysis are the lumbar spine, the proximal femur, and the forearm.[85] As there is often discordance between skeletal sites, ideally, at least, two different sites should be measured to assess fracture risk.[76,85,88] Prior to scanning, it is recommended to assess previous fractures, joint replacements, and bone diseases that might alter the shape or density of the bone, and identify any contra-indication (eg, pregnancy, recent use of oral contrast agent, recent isotopic study).[85] The patient is also required to remove any metal items (eg, belt, buckles, buttons, zippers, coins, keys). The correct positioning of the patient is crucial for acquiring adequate images.

Interpretation of DXA images is based on regions of interest (ROI).[89] For the lumbar spine, the ROI is L1-L4 or L2-L4, and should include at least two vertebrae, as shown in Figure 4. For interpretation of the proximal femur, ROI should include the femoral neck, the trochanteric region, Ward's triangle, and the total proximal femur (total hip) site, as shown in Figure 5. For analysis of the forearm BMD, ROI are radial shaft (33% or 1/3 radius) and ultradistal (UD) radius, as shown in Figure 6.

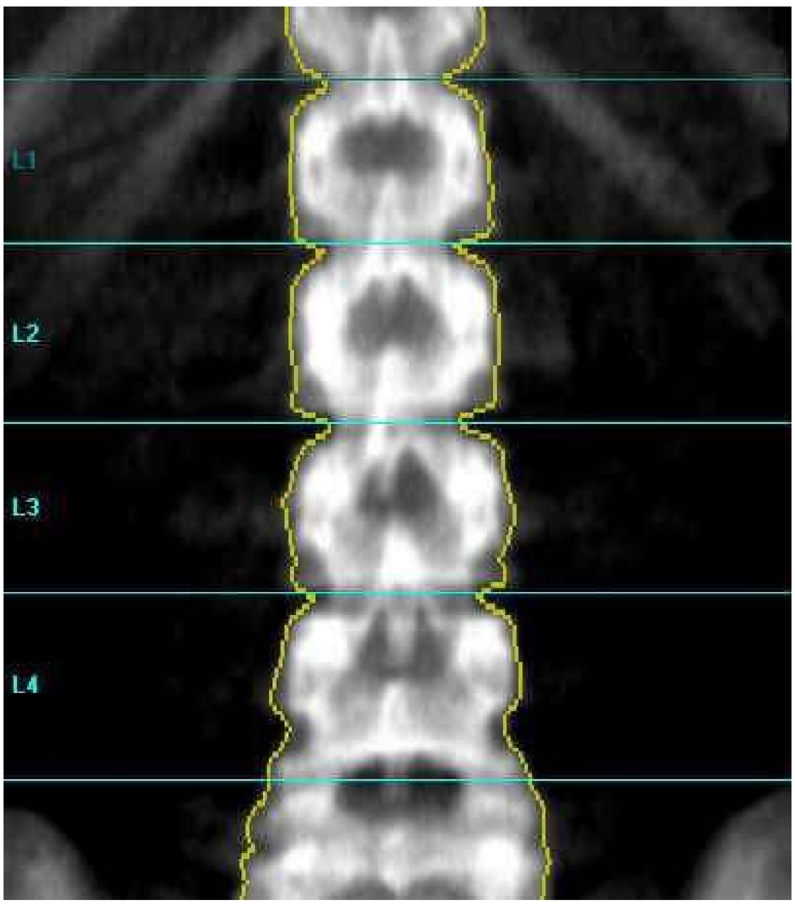
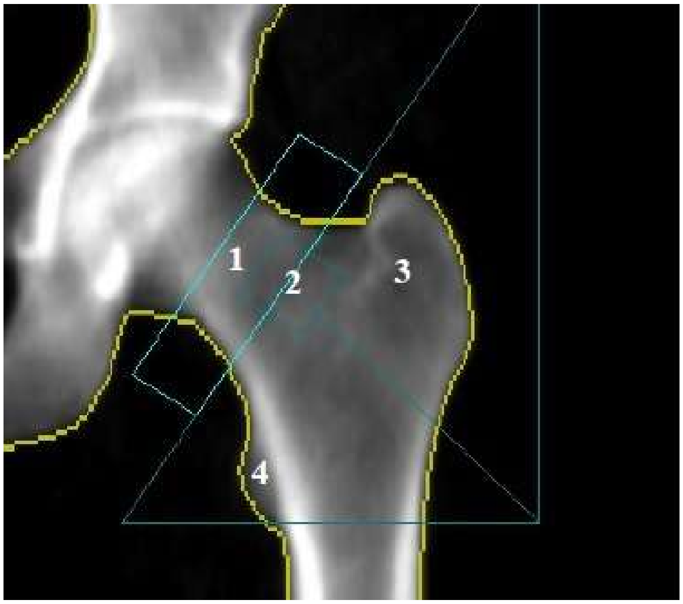


Figure 4: Lumbar spine ROIs



1 Femoral neck

2 Ward's triangle

3 Greater trochanter

4 Lesser trochanter

Figure 5: Proximal femur ROIs

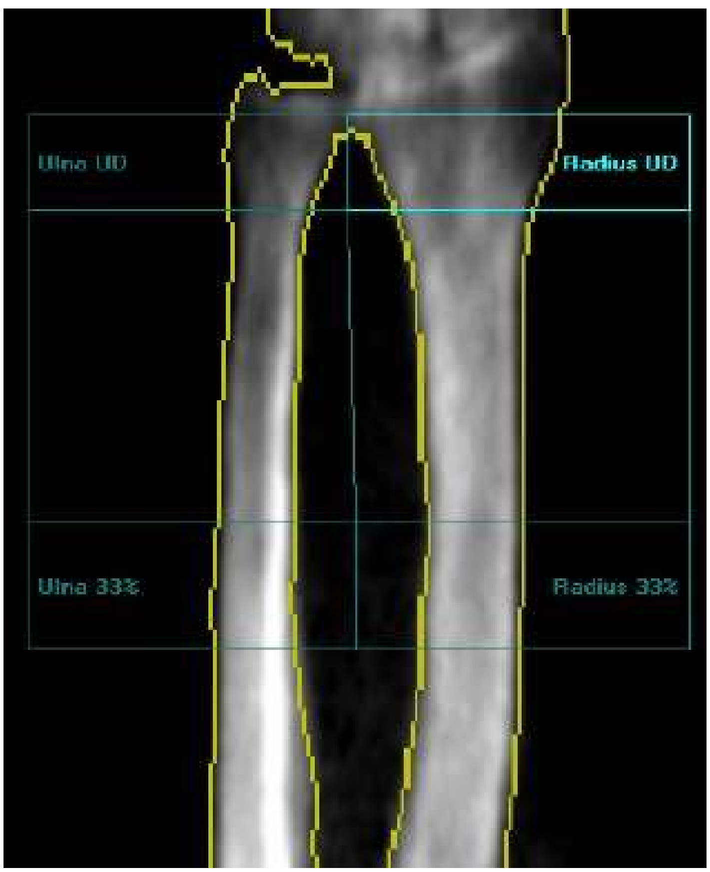


Figure 6: Forearm ROIs

The DXA total body scan can provide a simple and low-dose radiation methodology to measure the density of the three-component model: bone mineral, lean soft tissue, and fat. The measurement of total body BMD together with soft tissue composition is of interest for studies of nutritional requirements, growth and development, and also to assess skeletal status in both health and disease states.[85] Total body scans also allow the software to calculate BMC (in grams[g]), BMD (in g/cm^2) and bone area (in square centimeter [cm^2]) for the total body or for any of several anatomical subregions, and also for android and gynoid ROIs. This requires adjustments of cut locations to isolate these different regions of the body. The standard anatomical regions are: head, arms, legs, and trunk.

In terms of precision, the reproducibility of DXA is reported to be in the order of ±1% for the spine and ±2% for the femur; however, in clinical practice it can be less precise, as high as ±3%.[84,85]

To ensure that any patient's scans performed on the machine are accurate, and that DXA operators can be confident that follow-up scans will show real changes, it is necessary to follow Quality Assurance (QA) and Quality Control (QC) procedures.[85] Any variability detected during QA and QC could lead to inaccuracy in DXA results, leading to misdiagnosis and mismanagement for a patient. QA procedures, which are also referred to as internal QC procedures, require minimal operator input and check that the densitometer meets engineering specifications for: x-ray system performance; detector performance; tissue and bone measurements; and mechanical adjustments. It is recommended that this procedure should be executed at least three times per week, and any day when a patient or research participant is scanned. QC procedures involve the scanning of a phantom, supplied by the manufacturer, with a known area, BMD and BMC. This provides information on longitudinal and long-term variation, stability and precision of the densitometer, as one aspect of overall QA/QC.

Other bone densitometry technologies

Bone density accounts for 60 to 80% of the variance in ultimate bone strength. Other important determinants of bone quality are bone material properties, geometry (ie, size, shape and distribution of bone mass) and trabecular architecture. Techniques have been developed to explore these aspects and are capable of predicting both site-specific and overall fracture risk. They are accurate and highly reproducible, when performed according to accepted standards. The main limitation common to all these techniques is that the T-score derived from them cannot be used in conjunction with the WHO diagnostic criteria, as they are not equivalent to T-scores derived from DXA.[48,76,85] These densitometric techniques are:

- Conventional X-rays;
- Quantitative Ultrasound (QUS);
- Quantitative Computed Tomography (QCT);
- Peripheral QCT (pQCT);
- High-resolution QCT (HR-QCT, micro-QCT);
- Magnetic Resonance Imaging (MRI);
- Peripheral dual-energy x-ray absorptiometry (pDXA);
- Digital X-ray Radiogrammetry (DXR).

Biochemical markers of bone turnover

Bone mineral density, via DXA or other bone densitometry technologies, reflects a static condition of bone health, and, therefore, does not provide information about the dynamic process of bone remodeling. In contrast biochemical markers of bone turnover can be used to detect changes in bone turnover rates as early as 2 weeks after some therapies, and between 3 and 6 months after most.[90]

Biochemical markers can predict fracture risk independent of BMD and reflect aspects of bone strength other than the amount of mineralized bone tissue.[91] When above the reference range, biomarkers indicating bone resorption are associated with a two-fold increase in the risk of hip fracture, which is comparable with the risk associated with a 1.0 SD decrease in BMD.[91] A combined approach of assessing both BMD and markers of bone turnover may improve fracture prediction in both men and women.[91] However, it is important to note that bone markers are not unique to bone, and are therefore influenced by non-skeletal diseases.

In summary, biomarkers of bone turnover may[90]:

- Predict the future rate of bone loss;
- Predict the risk of fracture;
- Be used to monitor responses to pharmacological treatment, such as the extent of fracture risk reduction (when repeated after 3–6 months of pharmacological treatment), the adequacy of patient compliance, and persistence with therapy.

The most common biochemical markers of bone turnover are listed below, and are classified according to the turnover activity they indicate[76,90]:

- Resorption markers (ie, osteoclastic activity):
  - Carboxy-terminal telopeptide cross-linked type 1 collagen (CTx);
  - Type 1 collagen amino-terminal telopeptide (NTx).
- Formation markers (ie, osteoblastic activity):
  - Osteocalcin (OC);
  - Bone-specific alkaline phosphatase (BALP);
  - Procollagen type 1 amino-terminal propeptide (P1NP).

It has been reported that the best marker for bone resorption is serum CTx, and the best marker for bone formation is serum P1NP.[91,92] This is mainly due to their wide usage and utility for fracture prediction,[91,92] but also because they have a shorter response time than other bone formation markers.[93] Nonetheless, a recent systematic review[90] reported that it is not possible to make recommendations on the choice of bone turnover markers to be used in routine clinical practice, due to heterogeneity and poor quality of the available evidence.

Non-pharmacological factors that affect bone health

Calcium

Calcium is the most abundant mineral in the body and an essential element in the human organism. As discussed earlier, calcium and phosphate combine to form hydroxyapatite crystals, which constitute the main component of the bone matrix. Approximately 99% of calcium is deposited in bones. Calcium is not only important to bone health, but also necessary to many cell functions, and essential for neuromuscular activity, blood coagulation, and normal cardiac function. The average adults' adequate level of calcium intake ranges from 800 to 1500 mg/day. Osteoporosis Australia recommends 1000 milligrams(mg)/day for adults, increasing to 1,300 mg/day for women over 50 and men over 70 years.[10] The best dietary sources of calcium are dairy products and green leafy vegetables, but bottled mineral waters enriched with calcium are also good sources.[48,94]

In spite of the importance of calcium to bone health, a recent systematic review and meta-analysis concluded that increasing calcium intake is unlikely to lead to a clinically significant reduction in risk of fracture.[95]

Vitamin D

Vitamin D is the most important regulator of calcium homeostasis. Together with parathyroid hormone, it promotes adequate mineralization of bones, and is essential for optimal bone health. The major active metabolite of vitamin D is 1α,25-dihydroxy-cholecalciferol [$1,25(OH)_2D_3$], which is liposoluble and is found in the adipose tissue. The majority of this metabolite derives from the conversion of 7-dehydrocholesterol in the skin by ultraviolet (UV) light, but also derives from diet, particularly some fish and dairy products. It is converted in the liver into 25-hydroxycolecalciferol [25(OH)D], which is the major circulating vitamin D metabolite and reflects vitamin D status.[48,96]

Regarding bone health, the main actions of vitamin D are[48]:

- Promoting absorption of calcium from the small intestine into the blood stream;
- Decreasing the excretion of calcium in the kidney;
- Promoting recruitment, maturation and action of bone cells and protecting osteoblasts from apoptosis;
- Promoting the incorporation of calcium into bone (mineralization);
- Protecting the microstructure of trabecular bone.

Vitamin D is measured in international units (IU), with a recommended daily intake of 200-400 IU to maintain adequate levels, and low levels of vitamin D are an established risk factor for poor bone health and osteoporosis.[48,96] However, a recent Cochrane systematic review concluded that supplementation of vitamin D alone appears unlikely to be effective in fracture prevention.[97] This same systematic review demonstrated that taking vitamin D plus calcium is important for prevention of hip fracture or any type of fracture. However, the authors recommend balancing the benefits against risk of negative side-effects, such as kidney stones, kidney disease, gastrointestinal disease or heart disease.

In Australia, adequate levels of vitamin D are indicated by values equal or superior to 50 nanomoles (nmol) per liter (L) at the end of winter, and 10 to 20 nmol/L higher during summer, in order to allow for a seasonal decrease in the winter months.[10] As UV light (ie, sunlight) is the main source of vitamin D, sun exposure is fundamental.

Caffeine

It has previously been proposed that caffeine may produce a negative calcium balance by increasing urinary and fecal calcium excretion[98] and decreasing intestinal calcium absorption efficiency.[99,100] It was also reported that caffeine exerts a direct effect on bone, mediated by cyclic adenosine monophosphate[101] and teratogenic effects on ossification.[102] Some studies reported that regions with more trabecular bone, especially the trochanter, were more susceptible to caffeine intake.[103] In addition, it has been suggested that the effect of caffeine intake on hip fracture was still present after adjustment for calcaneal bone density, indicating that caffeine might influence factors other than bone mass, such as bone quality, or even the risk of falling.[104] A meta-analysis, conducted by Liu et al.,[105] concluded that for fracture incidence, each additional cup of coffee per day is associated with a risk elevation of 4.9% for women and a risk reduction of 9% for men. However, this meta-analysis included only observational studies, which are subjected to confounding factors, such as level of calcium intake, and smoking status. Liu et al.[105] also reported publication bias towards positive results, which means that studies with positive results were more likely to be published and, therefore, included in the systematic review. Of note, two recent meta-analyses of prospective cohort studies did not suggest a statistically significant association between coffee consumption and risk of hip fracture.[106,107]

Alcohol

Bone formation can be affected by alcohol intake, with high intakes being associated with a decreased BMD. Alcohol has both direct and indirect effects on bone. The growth of mesenchymal stem cells in the bone marrow and their transformation into osteoblasts are inhibited by alcohol.[108] Alcohol also triggers the transformation of mesenchymal stem cells into adipocytes,[108] and has a dose-dependent suppressive effect on osteocalcin levels.[109]

However, it has been suggested that moderate alcohol intake does not affect negatively the bone tissue, and may be associated with improved BMD and reduced risk of fracture.[76] Nonetheless, alcohol intake above the level equivalent to two standard drinks per day for women or three standard drinks per day for men can decrease bone quality.[76,109] Consequently, limiting alcohol use to no more than one standard drink per day for women and no more than two standard drinks per day for men is recommended, where one standard drink equals 12 ounces (350 milliliter [mL]) of beer, 5 ounces (150 mL) of wine or 1.5 ounces (40 mL) of 80-proof (ie, 40% alcohol by volume) distilled spirits.[76,109]

Smoking

Besides being detrimental to overall health, especially to cardiovascular and pulmonary function, the use of tobacco also deleteriously affects the skeleton, and is considered a risk factor for osteoporosis. It has been suggested that several mechanisms may be responsible for the association between smoking and bone loss, including both direct and indirect effects on bone cells. A proposed direct effect is that nicotine affects cell proliferation, reducing bone formation and increasing bone resorption.[110] The indirect effect is related to accelerated bone loss by decreasing intestinal calcium absorption, and altering calciotropic and adrenal cortical hormone metabolism, which leads to increased rate of bone resorption.[110,111] It has also been suggested there is a correlation between smoking and other risk factors for osteoporosis, such as low BMI, decreased physical activity and poor diet.[110,112] The rates of bone loss are estimated to be 1.5 to two times greater for current smokers than for non-smokers.[109]

Physical Activity and Exercise

Physical activity and exercise are well known for the many benefits, both short and long-term, they can provide to overall health. In terms of bone health, the lack of gravitational loading on the musculoskeletal system observed in situations such as prolonged bed-rest and spaceflight leads to an increased rate of bone loss.[113-115] Conversely, regular weight-bearing or impact physical activity has been shown to be a good non-pharmacological approach to improve bone mass.

At the end of the 19th century, the hypothesis was raised that bone tissue can be affected by mechanical loading[116-118]; however, this hypothesis was only further investigated in the 1970's and 1980's, resulting in the "Utah Paradigm" and the definition of the term "mechanostat".[29,33,36,38,119] The "Utah Paradigm" stated that bone effector cells, such as osteoblasts and osteoclasts, are responsible for determining the structure and function of bones, along with soft tissue, such as ligaments and tendons. The term "mechanostat" is related to the identification of the weight-bearing and load-bearing bones, together with feedback systems, which influence many facets of bone metabolism, in both bone production and resorption. Further studies at a tissue-level contributed to the theory that bones are capable of positively adapting their mass, microstructure and strength when routinely exposed to a repeated external stimulus.[35,38,119-121] In addition, it was demonstrated that bone mineral density is highly associated with lean body mass.[30-32]

Previous research has demonstrated that muscle contractions increase loads on bones, producing stress and strain reactions in bone tissue,[35-37] and also that dynamic loading has a more positive effect on bone tissue than static loading.[38] These findings support the assertion that changes in muscle quality (ie, mass, size and strength) are directly related to changes in bone quality (ie, mass, structure and strength), as suggested by the functional "muscle-bone" unit concept.[33,34] Muscle forces are generated during both activities involving no impact, which are associated with muscle forces only, and impact, which incorporate both ground reaction and muscle forces. However, with regards to bone metabolism, it is not possible to conclude which aspect (ie, muscle forces or gravitational forces) is more relevant in generating positive results.[122]

To improve or maintain bone health, the American College of Sports Medicine (ACSM) guidelines[123] recommend that individuals should complete weight-bearing aerobic activities 3 to 5 days/week and resistance exercise 2 to 3 days/week, and that the intensity of resistance exercise should be at 60 to 80% of 1 repetitium maximum (RM) for 8 to 12 repetitions. It is also recommended that exercise sessions should last from 30 to 60 minutes and should involve bone impacting activity such as jogging or weightlifting. Recommendations from Osteoporosis Australia are in line with these recommendations.[10]

However, not all types of exercise are able to generate positive effects on bone metabolism.[18] Traditionally, only high-impact exercise, associated with high ground reaction forces, and high magnitude loading exercise, associated with joint reaction forces, have been associated with a positive osteogenic effect. [19,20,124-127] Some sporting activities are associated either with no effects on bone or with increased risk of fractures, due to bone loss.

For instance, Nichols and Rauh[128] analyzed the BMD of competitive male master cyclists, over a 7-year period, and compared it to the BMD of non-athletic active controls. After adjusting for body mass index, lean mass, calcium intake, and exercise habits, they demonstrated that cyclists had a greater decline in BMD than non-athletes, with more than 30% of the athletes who had osteopenia at baseline becoming osteoporotic after seven years, compared to only 5% of the non-athletes. In line with this finding, a systematic review conducted by Olmedillas et al.[129] concluded that road cycling does not appear to confer any significant osteogenic benefit. Scuba diving, a sport that, due to its unloading effect, can be compared to other weightlessness activities, such as spaceflight and bed-rest, is also known to negatively affect bone metabolism. Pereira Silva et al.[21] reported that scuba divers had a mean femoral neck BMD that was 4.6% lower than that of a non-diving control group. In this study, both groups were sedentary, differing only in the scuba diving activity. The effect of walking, a low impact exercise, on BMD was analyzed by a systematic review and meta-analysis conducted by Ma et al.,[130] and it was concluded that this exercise can only positively affect BMD at the femoral neck, with no significant effects at the lumbar spine, radius, or for the whole body, in perimenopausal and postmenopausal women.

Howe et al.[131] conducted a Cochrane systematic review to investigate the effectiveness of exercise in preventing bone loss and fractures in postmenopausal women. They analyzed forty-three randomized controlled trials (RCTs), with a total of 4,320 individuals, and found that the type of exercise associated with the greatest femoral neck BMD was non-weight-bearing, high-force exercise, such as progressive resistance strength training for the lower limbs. With regards to BMD at the lumbar spine, an association of exercise programs, involving resistance training, aerobics, and high impact activity, was found to be more effective.

Basat et al.[132] conducted a 6-month RCT, comparing the effects of strengthening and high-impact exercise to the effects of a control condition (ie, no exercise) on BMD and bone turnover markers in postmenopausal women. They concluded that increases in BMD at the lumbar spine and femoral neck were significantly greater in the high-impact group than in the strengthening and control groups. Also, they concluded that the bone formation marker osteocalcin (OC) significantly increased (p=0.033) and the bone resorption marker N-telopeptides of type I collagen (NTx) significantly decreased (p=0.034) only in the high-impact group.

A meta-analysis of randomized controlled trials conducted by Marques et al.[133] investigated exercise effects on BMD in older adults (males and females, aged between 65 and 83 years). They analyzed 19 studies, incorporating a total of 1,577 participants. They concluded that interventions involving mixed loading impact significantly increased BMD, in the order of 0.011 g/cm2 (95% confidence interval [CI] 0.003 to 0.020 g/cm^2, p=0.07) for the lumbar spine and 0.016 g/cm2 (95% CI 0.005 to 0.027 g/cm^2, p =0.004) for the femoral neck. They also concluded that low impact exercise protocols were ineffective in reducing bone loss. Combined loading studies found impact activity mixed with high-magnitude joint reaction force loading through resistance training were effective at the lumbar spine. Odd-impact (eg, aerobics) interventions were also effective in increasing BMD at the lumbar spine and femoral neck.

- Water-Based Exercise

The literature is inconsistent in its reports of the effects of exercise executed in the water environment, often called water-based exercise, on bone health of middle-aged and older adults. Exercise executed in the water is known to have a reduced weight-bearing component. However, the properties of water as an exercise medium mean it is still able to produce some demands on the bone by providing resistance to movement and so influencing muscle forces and strengthening.

Some observational studies that have investigated swimmers have reported that participants of this sport have similar, or sometimes lower, BMD when compared to sedentary controls, indicating swimming is associated with a similar or greater risk of bone deterioration and its consequences when compared to a sedentary lifestyle.[22,134,135] Velez et al.[22] reported that mature aged males who restricted their physical activity to only swimming had a 10% higher prevalence of osteoporosis when compared to sedentary age- and sex-matched controls.

Conversely, Gomez-Bruton et al.[136] conducted a systematic review analyzing the effects of swimming on bone tissue, analyzing 64 studies. It was reported that this sport has no negative influence on bone health and might have benefits later in life. In addition to this, in a cross-sectional analysis, Balsamo et al.[23] concluded that aquatic exercise might be a non-pharmacological strategy to prevent bone loss in postmenopausal women. However, most of what is known about the effects of water-based exercise on bone health relies either on observational studies or on conflicting results found in randomized controlled trials (RCT's). For instance, Rothstein et al.[137] investigated the effect of water exercise, conducted over a period of seven months, on BMD and compared this to the effects observed in sedentary controls. They concluded that a well-planned water exercise program can have a positive effect on bone density in post-menopausal women. These findings were in line with those of Tsukahara et al.,[138] who conducted a 1-year longitudinal study, and concluded that water exercise is an important exercise mode for preventing bone loss. Vanaky et al.[139] conducted a RCT over 12 weeks investigating the BMD of post-menopausal women after a water exercise program, and compared them to a sedentary group. They concluded that the water exercise program had a positive effect on bone density, whereas the control group showed bone loss. Similar findings were demonstrated in a RCT conducted by Moreira et al.,[140] who compared an aquatic exercise group to a sedentary control group, analyzing bone health through bone biomarkers (CTx, P1NP) and DXA. After 24 weeks of intervention, they concluded that, when compared to the control group, the intervention group (water exercise) had an attenuated bone resorption and enhanced bone formation, which prevented these individuals from incurring a reduction in the trochanter BMD, as was observed in the control group. In contrast, Pernambuco et al.[141] conducted a RCT over 8 months, comparing the effects on BMD of an aquatic aerobics group to effects in sedentary controls, and did not demonstrate improvement in BMD at the lumbar spine and total femur, with no statistical differences observed after the intervention period between the groups.

To date, with regard to bone health, no systematic review of the effects on bone of water-based exercise other than swimming has been found. Therefore, the effects of exercise undertaken in a water environment on bone health of middle-aged and older adults remain uncertain.

At present, only one publication has investigated bone health in surfers. This study was conducted by Climstein et al.[51] and used a cross-sectional observational design. The researchers analyzed the bone health of 11 middle-aged male surfers with a minimum of 40 years of surfing experience, not participating in any other physical activity, and compared them to 10 age and gender-matched sedentary controls. Outcomes investigated included BMD, BMC, segmental body composition, and serum bone biomarkers (ie, CTx and P1NP). The results demonstrated that the surfers had a statistically greater BMD in the arms, trunk, ribs, spine and pelvis when compared with the sedentary controls, and a statistically nonsignificant trend towards lower CTx, indicating less bone resorption, and greater P1NP, indicating higher bone formation. The authors concluded that surfing appears to be advantageous with regard to BMD and BMC. However, the positive findings were limited to the upper body segments, and they recommended surfers participate in progressive resistance training exercise to improve the BMD of their legs, in order to reduce their risk of hip fracture in later life. However, two major limitations of this study are the small sample size and the fact that it did not utilize standard clinical sites of assessment of BMD.

Surfing

The history of surfing began with the ancient Polynesians, and it has been practiced for many centuries and by different cultures. For instance, it was an integral part of the Hawaiian culture, considered the sport of the kings.[142] However, by the late 19th century, the sport almost completely vanished because it was strongly discouraged by religious missionaries. Duke Kahanamoku, an exceptional Hawaiian aquatic sportsman and Olympic champion, who was a gold medal winner in the 100m freestyle in the Olympic games in Stockholm (1912), is considered to be responsible for the resurgence of the sport and for the birth of modern surfing, dedicating time to demonstrate the sport all over the world.[143,144]

It is believed that surfing was first brought to Australia by Tommy Walker, who in 1910 demonstrated the sport at Manly Beach, Sydney, with a 10-foot surfboard bought at Waikiki beach, Hawaii, for two dollars.[145] After becoming an expert rider, Walker gave several exhibitions in Sydney in 1912.[146] However, the sport only received national exposure in December 1914, with exhibitions by Duke Kahanamoku, who demonstrated the board riding technique at Freshwater Beach, in Sydney.[147] The first Australian Board Riding Championship was held in

1924, and was won by Claude West, who was taught by Duke at Freshwater beach.[148] It was not until the 1950s that popularity of surfing started to grow, when a group of Hawaiian and Californian lifeguards, led by Greg Noll, were on tour during the Melbourne Olympics (1956).[149] They demonstrated their new Malibu surfboards, becoming known as Mal, which were much lighter than those used on Australian beaches at that time, making the sport more convenient. In 1964, the first official surfing world championship took place in Australia, at Manly Beach, Sydney.[143]

Surfing has significantly changed over the years in terms of equipment, competition, safety and participation globally. Equipment has changed from the traditional wooden boards to the high technology shaped fiberglass used nowadays. Competition has changed from being a friendly amateur sport to a globally televised professional world surfing tour, with millions of dollars in sponsorship and prize money. Beach safety has improved greatly over time, led in Australia by the not-for-profit community organization Surf Life Saving Australia (SLSA), with professionals and volunteer lifeguards on beaches all over the country. These factors have influenced participation in this sport, changing it from being a sport mainly practiced by men to being a sport for all ages, genders and cultures.

Nowadays, surfing is a popular recreational activity and competitive sport, and also is one of the fastest growing sports in the world. It is estimated that there are around 37 million surfers worldwide,[44] a statistic which has doubled when compared to the 18 million surfers estimated in 2002.[45] In Australia, this number is estimated at 2.7 million, which accounts for over 1 in 10 Australians, with approximately 420,000 annual Surf School participants.[46] In addition to this, around a third of non-surfers would be interested in learning to surf.[46]

Despite the remarkable growth and the continuously increasing number of participants worldwide, scientific research on surfing does not reflect this growth in comparison to most other mainstream sports.[47] Given that surfing's popularity started to grow in Australia in the 1950s and 1960s, many of the original surfers are now past the age of 55, with a considerable number of middle-aged and older surfers continuing the activity. However, due to lack of research on surfing, it is not possible to make recommendations to promote the bone health of surfers in these age groups.

The process of surfing was described by Lowdon[150] as an activity that consists of:

- Lying on a surfboard in a prone position;
- Paddling out in order to reach the appropriate zone to catch a wave, known as the take-off area;
- Performing powerful strokes when the wave approaches, giving the board enough speed to be gathered up by the swell;
- Quickly standing up once the wave is caught (pop-up);
- Performing maneuvers as the wave breaks.

On this basis, surfing is recognized as a quasi-weight bearing (ie, having a partial load component) aquatic based physical activity, which can be either recreational or competitive in nature. Surfers spend approximately 97% of the time in a weight-supported environment, for example with arms paddling while lying in a prone position on the board or sitting on the board waiting for waves, with small differences in reported time allocations between recreational and competitive surfing.[49,50,151,152] Time-motion analyses[49,50,153] of recreational surfers found that actually standing up on the board and riding a wave typically accounts for only three minutes in a 60-minute surf session, ranging from 2% to 8% of total surfing time. This would afford the bones little stimulus for remodeling due to the activity. Therefore, it might be expected that participants in this aquatic activity may have an imbalance between osteoclastic (bone resorption) and osteoblastic (bone remodeling) activity, resulting in degradation of BMD and subsequently exposing surfers to premature development of osteoporosis and increased risk of fractures.

In spite of the fact that surfing is considered a quasi-weight bearing aquatic based physical activity, it has several key physiological aspects. It requires a wide range of physical actions, including:

- Paddling-out, which involves aerobic and anaerobic power, intermittent endurance and strength/power of the upper body;
- Passing through waves (ducking under white water);

- Catching a wave;
- Balancing on the surfboard;
- Executing and completing maneuvers, which involves balance, force control, flexibility, reaction time, and coordination.

Moreover, surfing is influenced by a wide range of environmental conditions, for example different wave sizes and formats, rip currents, temperature of the water, winds, and the number of surfers in the line-up (line-up situation), which is the area where the surfers position themselves to wait for a wave. Duration also varies, from a short period of time, for example 20-30 minutes in a competitive situation, to as long as 5-6 hours during good wave conditions in a practice or recreational session. With the above dynamic requirements, surfers are exposed to intermittent exercise bouts, with different upper-body demands, for example arm paddling, when compared to lower-body demands, for example wave riding.[152] These dynamic exercise bouts promote benefits to the cardiovascular system, improving shoulder, back, leg, and core strength, and also improving balance. Figure 7 (adapted from Mendez-Villanueva et al.[152]) shows different physiological aspects of surfing.

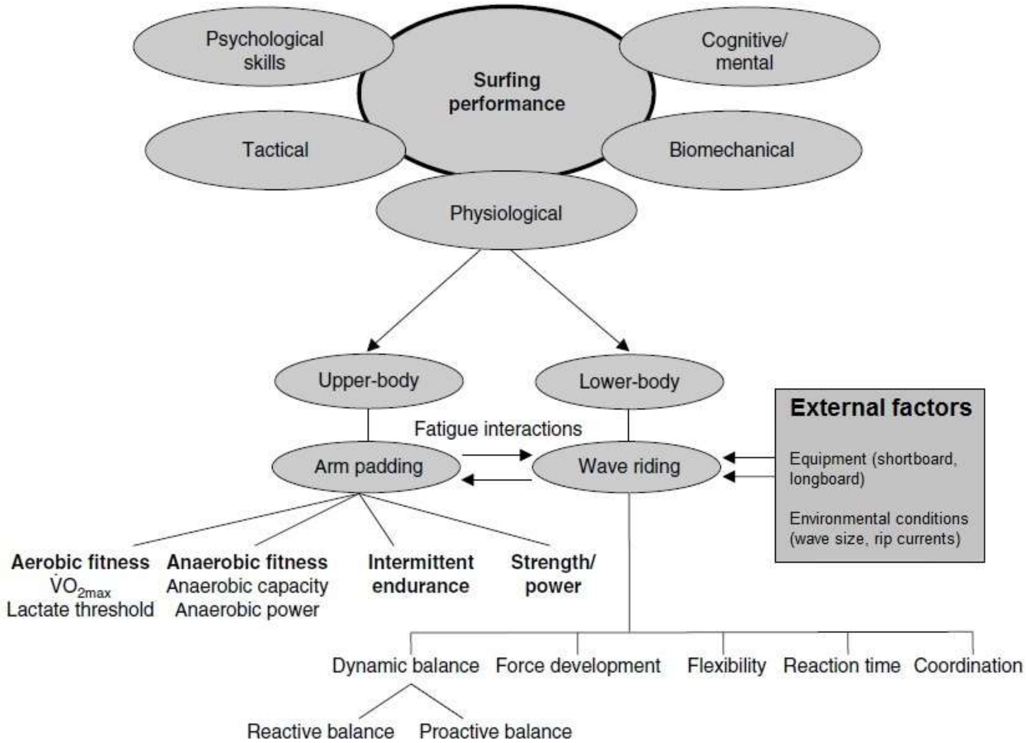


Figure 7: Physiological aspects of surfing

Modified from: Mendez-Villanueva A, Bishop D. Physiological aspects of surfboard riding performance. Sports Med. 2005;35(1):55-70[152]

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Frank et al.[154], analyzed the effects of long-term recreational surfing on control of force and posture in older surfers. They recruited 11 healthy surfers, with a mean age of 60±2.3 years, who were participating in recreational surfing at least twice per week and had surfing experience of over 40 years, and compared them to an age-matched healthy control group with mean age 59.6±2.5, who were physically active. Neither group participated in any systematic strength training in the 6 months prior to the study. Frank et al. analysed maximal isometric voluntary contraction force (MVC), rate of force development, steadiness in muscle force production (knee extensors and flexors, and ankle dorsi- and plantarflexors) at 5%, 15% and 25% of MVC levels, joint position sense, and body sway in a standing position. They concluded that long-term participation in recreational surfing caused specific neuromuscular adaptations in control of muscle force production and posture, with surfers demonstrating a better ability in controlling steady muscle contraction than age-matched, physically active controls. However, there were no significant differences between the groups with respect to lower body strength and power. The authors attributed this to the fact that the control group was involved in regular exercise, such as walking, cycling, and swimming, 2-3 times per week, and that the effects of surfing on lower body strength and power were similar to the effects of regular physical activity performed in various combinations by active non-surfers.

Some studies have indicated that, in terms of impact on bone health, the characteristics of a proposed exercise, which include dynamic components of the exercise, play a fundamental role,[39-43] with dynamic loading being considered to have more positive effect on bone tissue than static loading.[38] In line with this, and as noted earlier in this chapter, Climstein et al.[51] reported that surfers had a statistically greater BMD in the arms, trunk, ribs, spine and pelvis when compared with sedentary controls, and a statistically non-significant trend towards lower serum CTx (indicating less bone resorption) and greater serum P1NP (indicating higher bone formation). They concluded that surfing appears to be advantageous with regard to BMD and BMC. However, these findings were based on a small sample size, and not based on traditional clinical sites recommended to investigate bone health. To date, the study by Climstein et al.[51] is the only study that has analyzed the bone health of surfers.

Surfing Injuries

A great variety of factors can affect surfers' health, ranging from acute injuries to conditions arising from chronic environmental exposure. Injuries can be traumatic or non-traumatic, and are classified as either acute or chronic. The mechanism of injury can be direct trauma from a surfboard (caused by contact with the rider's own board or another surfer's board), contact with the sea floor (eg, sand, coral reef, rocks), hydraulic force of a wave, excessive body motion during manoeuvres, contact with marine animals (eg, jellyfish, sea urchins, stingrays, dolphins, seals, whales, sharks), or other environmental mechanisms (eg, sun exposure, or exposure to rip currents, water temperature, wind). A wide range of injuries can occur, both: acute, such as lacerations, concussions, contusions, tympanic membrane rupture, fractures, dislocations, sprains, and strains; and chronic, such as overuse injuries, exostoses, and otitis externa.

Table **6** shows common acute and chronic injuries derived from surfing. Serious health consequences are uncommon; however, have occurred at times. These include myelopathy, which is a rare cause of non-traumatic spinal cord injury, resulting in paraplegia and paraparesis, first described in 2004.[155] This condition is more common in novice surfers who have been lying prone on a surfboard with the lumbar spine hyperextended for prolonged periods of time.[156] Drowning is also a serious consequence, with surfers accounting for 15% of all drowning victims,[157] and there were 35 drowning death incidents related to surfing from 2004 to 2013.[158]

Table 6: Common injuries related to surfboard riding

Acute injuries	Chronic injuries
Lacerations	Overuse motion injuries (eg, shoulders, back, knees)
Sprains	Exostoses of the external auditory canal
Strains	Otitis externa
Contusions (eg, dislocations, fractures)	Inflammations, infections
Concussions	
Hazardous marine life (eg, envenomation/attack)	
Tympanic membrane rupture	

One of the first studies on the prevalence of surfing injuries was published in 1977, and was conducted by Allen et al.,[159] who analyzed surfing injuries at Waikiki (Oahu, Hawaii) through a 56-month survey involving 36 hospitalized patients. They reported the risk of injury related to surfing was approximately one injury resulting in hospitalization per 17,500 surfing days, concluding that this injury rate was far below the rate for most sports. In Australia, one of the first studies reporting surfing injuries was conducted by Lowdon et al.,[160] and published in 1983. They analyzed traumatic injury data from 346 Australian surfers and reported that lacerations represented 41% of all injuries, followed by dislocations, sprains, strains and fractures. It was reported that the rate of moderate and severe injuries among the sample was 3.5 injuries per 1,000 surfing days.

The first large study of acute and chronic surfing-related injuries was published in 2002 by Nathanson et al.,[45] with similar findings. They analyzed 1,348 surfers of diverse abilities, from 48 countries, in an observational, retrospective internet-based survey. They reported that 67% of injuries were caused by surfboards, 34% of injuries were to the head, and laceration was the most common type of injury (42%), followed by contusions, sprains and strains. They also found that 37% of the participants reported chronic injuries. Of these, 57% were strains, mainly in the shoulder, back, and neck areas, and 14% were bony outgrowths (or exostoses) of the external auditory canal (EAC), or surfer's ear. Finally, they reported that older surfers, more advanced surfers, and those surfing in large waves were at higher risk of suffering significant injuries.

In a study conducted on Victorian beaches, in Australia, Taylor et al. [161] analysed injury data from 646 surfers (90.2% male, median age 27 years, 10 median years of surfing), and reported that more than 20% of the participants experienced chronic health problems, including chronic/recurrent otitis externa and exostosis of the EAC.

To date, the largest Australian national survey on surfing-specific injuries was conducted by Furness et al.,[47,65] who analyzed injury data from recreational and competitive surfers, reporting both acute[47] and chronic[65] injuries. They conducted an online survey and included 1,348 participants (91.3% males), reporting an incidence rate of 1.79 (95% CI 1.67-1.92) major injuries per 1,000 hours of surfing. Major injuries were defined as requiring one day or more off work and/or surfing and/or the participant required treatment from a health professional. Shoulder, ankle and head/face regions were the most common body locations of major acute injuries. These injuries were predominantly of muscular and joint origin, and the most common mechanism of injuries was direct trauma. Key factors that increased the risk of sustaining an acute injury included competitive status, hours surfed (>6.5 hours/week), and the ability to perform aerial maneuvers. With regard to chronic injuries, 35.4% of the participants reported suffering a chronic condition caused or aggravated by surfing. A total of 1,068 chronic injuries were reported, and the lower back, shoulder and knee were most commonly involved. There was no significant association between prevalence of chronic injury and hours spent surfing. Regarding the nature of the chronic injuries, musculoskeletal injuries were the most common. Joint injuries represented 43.5% of chronic injuries, and muscular injuries 23.6%, with only 7.7% being non-musculoskeletal injuries, which included auditory exostosis, otitis externa and pterygiums (also known as surfer's eye, which is a tissue that grows from the conjunctiva).

Exostosis of the external auditory canal

Exostosis of the external auditory canal is recognized as a potentially serious complication of surfing, and is commonly referred to as surfer's ear, even though it has also been described in other sports.[61,63,162,163] Auditory exostosis has been reported in several ancient populations all over the world, mostly in individuals with intense contact with water.[164] One of the first studies reporting exostosis of the ear canal was published in the late 1800s and the authors associated it with water sports in general.[165] Auditory exostosis is diagnosed by identifying an abnormal bone outgrowth that arises from the temporal bone and protrudes into the ear canal, via otoscopic examination of the ear.[52,53,166] Figure 8 shows otoscopy images demonstrating the difference between a normal healthy auditory canal and an auditory canal with multiple exostoses.

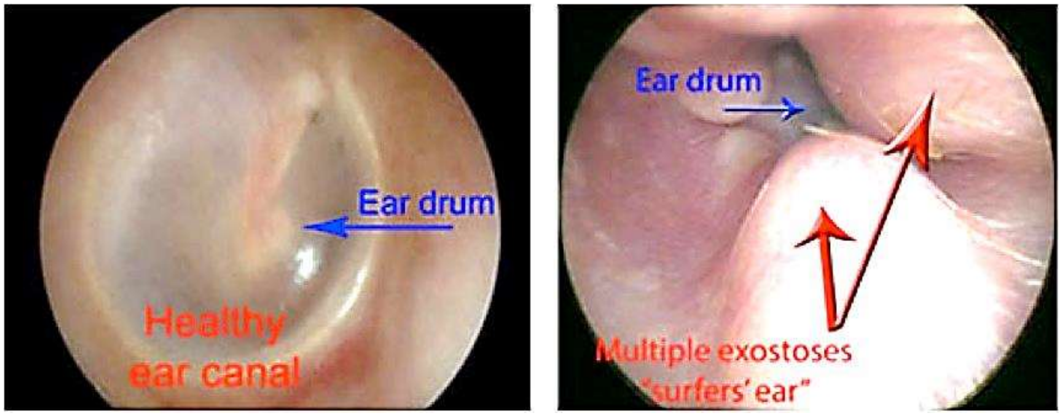


Figure 8: Otoscopy showing healthy auditory canal (left) and exostoses of the auditory canal (right)

Auditory exostoses are commonly multiple and found bilaterally. Exostoses are usually asymptomatic; however, patients can present with a prolonged blocked feeling of the ears following water activities, chronic cerumen (ear wax) impaction, frequent ear infections (recurrent otitis externa), pain (otalgia), and conductive hearing loss (deafness).[52,57,166] Nathanson et al.[45] reported that exostoses often result in partial or complete deafness, and many require surgical correction. In a study that investigated acute injuries and chronic pathology of the head and face sustained while surfing, it was reported that 100% of surfers who were imaged specifically due to hearing loss were noted to have bony exostoses within both external auditory canals.[168] The prevalence of this type of injury in surfers, both professional and recreational, ranges from 38 to 80 percent, when investigated by otological examination.[58,64,169-173]

Australian surfers are considered to have a high incidence of exostoses of the ear canal.[64,174,175] However, only two studies have analyzed the prevalence of exostoses in Australian surfers. Hurst et al.[64] assessed 300 surfboard riders (229 males, mean age 32.6±11.3 years, and 71 females, mean age 24.5±9.4 years). Participants were recruited from two different locations in Victoria (Bells Beach and Phillip Island). Surfers were compared to swimmers and to a control group. The authors found a prevalence of 78 percent of auditory exostoses in male surfers and 69 percent in females. After adjusting for exposure, there was no difference in prevalence of exostoses between men and women. It was reported that surfers were 12 times more likely to develop this injury than swimmers. The level of exostoses in the right ear was found to be significantly greater (p=0.005) than in the left ear. This was attributed to the fact that surfers typically face out to sea watching for the next set of waves, which positions the surfers such that their right ear is facing the prevailing wind. The authors reported that surfers with greater than 20 years of regular exposure had a one in two chance of developing severe exostoses. The mean water temperature in the region where the study was conducted was 15.9°C (ranging from 13.8°C to 18.2°C)[176]. In another study, Furness et al.[65] conducted an online survey to investigate self-reported lifetime incidence of chronic injuries. 3.5% of the surfers reported they had exostoses (3.1% in recreational surfers, 4.3% in competitive surfers), a number considerably different to that reported by Hurst et al.,[64] likely in part because some with exostoses were unaware of the exostoses.

With regard to the risk factors for auditory exostoses, genetic predisposition does not appear to have an influence, or is considered to only play a minor role in their development.[177,178] Exostoses affect males and females, with no gender protection.[64] There is no data available to date regarding the influence of any type of medication in developing auditory exostosis or affecting its severity. It is well known that there is a positive association between the amount of time spent surfing and the presence and severity of exostoses of the ear canal, with risk increasing after only five sessions per month,[52,64,170,171,179] and significantly increasing after five years of surfing.[169,170,179] Cold water exposure is commonly cited as an important risk factor. Kennedy[180] investigated the relationship between auditory exostoses and cold water in a latitudinal analysis. Higher frequencies of such exostoses were found in the middle latitudes (30-45 degrees North and South, with water temperature below 19°C). However, in latitudes between 0-30 degrees (North and South, water temperature above 21°C), auditory exostoses had very low frequency, or were even absent. In a study conducted in New Zealand, Chaplin et al.[170] reported that exostoses of the external ear canal were more common and more severe in cold water (South Island) than in warm water (North Island). These findings are in agreement with other studies, with prevalence of such exostoses in cold water ranging from 61 to

80%, in water temperatures varying from 8°C to 19°C.[58,60,64,169-173,178] Similarly, in a study conducted in Japan,[173] authors reported that more severe auditory exostoses (grade 3) were more likely to be formed in cold water surfers than in warm water surfers if the surfing index score was equal in both groups. However, this difference between groups was not statistically significant. A study conducted in the USA[58] showed consistent findings, and the authors again reported that auditory exostoses were more likely to be found in cold water surfers (odds ratio [OR] 5.8, p=0.0001) than in warm water surfers, though the difference in severity did not reach statistical significance, and they concluded that it is difficult to precisely quantify a surfer's exposure to cold water. In a study that evaluated 621 prehistoric human skulls[164] from populations who lived in proximity to the ocean and were dependent on it for their subsistence, although an association with winter and wind was found, auditory exostoses were not identified, and the mean ocean temperature was at or above 19°C. Wind exposure,[59,60,64,169,181] and its association with cold water,[61-63] has been described as a factor that affects both the incidence and the severity of auditory exostoses.

Only two studies have reported auditory exostosis in surfers exposed to water temperature above 19°C, with an observed prevalence of 38% (United States of America [USA], sea temperature from 15.6°C to 35°C)[58] and 59.8% (Japan, sea temperature from 16°C to 28°C).[173] It is important to note that, in both studies, surfers were not exclusively exposed to warm water. Therefore, there is a lack of research describing the prevalence and severity of auditory exostosis in surfers who spend the majority of time surfing in warm water (above 19°C), in order to make recommendations for this specific population. The Gold Coast region of Queensland has a mean water temperature of 24°C throughout the year, ranging from 19°C (August) to 28°C (February),[182] and is thus an ideal environment in which to assess the prevalence of auditory exostoses in warm water surfers.

The precise mechanism for the development of exostoses of the external auditory canal remains unknown. Cold water exposure is believed to stimulate osteoblasts within the temporal bone, leading to bone growth into the ear canal, possibly as a mechanism to protect the tympanic membrane against low temperatures.[178,183] Notably, it has been reported that a cohort of four patients had significant recurrence of auditory exostosis even though they had stopped surfing and were no longer exposed to cold water.[62] It has been proposed that the temporal bone may have become unstable, undergoing spontaneous osteogenesis (bone formation), in these surfers.[178] With regard to the wind effect, it has been proposed that evaporative cooling would result in greater progression of exostoses in the ear more exposed to a predominant wind[64,169,181]; however, some studies did not find significant differences in prevalence and severity between the ears, even though one ear was typically more exposed to wind than the other.[178]

Regarding severity, auditory exostosis is clinically classified into four grades, based upon the percentage of obstruction of the ear canal, as assessed by otoscopy: grade 0 (no obstruction, no visible exostosis); grade 1 (obstruction of 1%-33%); grade 2 (obstruction of 34% to 66%); and grade 3 (obstruction of 67% to 100%).[64,173,178,179] The rate of growth is unknown.

Prevention remains unclear, but regular use of earplugs may help prevent the occurrence of auditory exostoses,[56,62] and this is recommended by the American Academy of Family Physicians.[184] However, in the study conducted by Nathanson et al.,[45] only 17% of surfers reported using earplugs. In addition, in a study conducted in the United Kingdom, Reddy et al.[56] reported that 60% of surfers knew about the potential preventability of auditory exostoses, but only 2% admitted regular use of water precautions, such as ear plugs or hoods. They also reported that surfers with an awareness of preventability were significantly more likely to use water precautions, and concluded that health promotion may increase the use of water precautions in the prevention of auditory exostosis. The primary reason for surfers avoiding the use of earplugs is the hearing impairment associated with their use. As a result, some authors recommend soft prefabricated earplugs as the preferable model, as they are associated with less hearing impairment when compared to other models, while customized earplugs made of hard material result in the greatest impairment of hearing.[185] However, the benefit of wearing ear protection to prevent exostoses is controversial, with some authors reporting no benefits from wearing earplugs.[64,170]

Surgical correction is the only treatment available for auditory exostoses, and it is usually reserved for individuals with severe exostoses (occlusion equal to or greater than 67% of the canal) and symptomatic exostoses.[52] This procedure does not prevent recurrence, and exposes the individual to potentially serious complications, such as rupture of the tympanic membrane, sensorineural hearing loss, facial nerve injury, infection, delayed healing, and stenosis.[55,62,174,186]

Conclusion

The purpose of this chapter was to review the literature on bone health and surfing. It was evident from the review that there were gaps in the research evidence regarding these topics. Key issues identified through the review were in relation to the skeletal health of surfers and exostoses of the external auditory canal in this population. In addition to this, the effects of water-based exercise on bone health of middle-aged and older population remain uncertain. On this basis, this program of research focused on addressing these gaps.

Chapter 3: Effects of water-based exercise on bone health of middle-aged and older adults: a systematic review and meta-analysis

Preface

This chapter is part of the first major research area of this thesis, focused on skeletal bone health, and is complemented by Chapters 4 and 5.

As previously mentioned in Chapter 2, a gap exists in relation to knowledge of the effects of water-based exercise on skeletal bone health of middle-aged and older adults. Therefore, this chapter aimed to provide an up-to-date and comprehensive synthesis of all available evidence regarding the bone health of middle-aged and older adults involved in water-based exercise. To this end, a systematic review of the literature was conducted in order to identify, synthesize and analyze all relevant research findings on this topic. This chapter is documented in accordance with the recommendations of the Cochrane Handbook for Systematic Reviews of Interventions.[187]

The systematic review documented in this chapter was published in the Open Access Journal of Sports Medicine and is formatted according to the journal's guidelines. A copy of the published manuscript is included in Appendix I.

***Simas V**, Hing W, Pope R, Climstein M. Effects of water-based exercise on bone health of middle-aged and older adults: a systematic review and meta-analysis. Open Access J Sports Med. 2017 Mar 27;8:39-60. doi: 10.2147/OAJSM.S129182.*

Abstract

Background. Age-related bone loss is a major health concern. Only exercises associated with high-impact and mechanical loading have been linked to a positive effect on bone turnover; however, these types of exercise may not always be appropriate for middle-aged and older adults due to physical decline or chronic disorders such as osteoarthritis. Water-based exercise (WBE) has been shown to affect different components of physical fitness, has lower risks of traumatic fracture and applies less stress to joints. However, the effects of WBE on bone health are unclear.

Objectives. This study aimed to explore whether WBE is effective in preventing age-related bone deterioration in middle-aged and older adults.

Methods. A search of relevant databases and the references of identified studies was performed. Critical narrative synthesis and meta-analyses were conducted.

Results. Eleven studies, involving 629 participants, met all inclusion criteria. All participants were postmenopausal women. Eight studies compared WBE to a sedentary control group (CG), and four had land exercise (LE) participants as a comparison group. Meta-analyses revealed significant differences between WBE and CG in favor of WBE for changes in bone mineral density (BMD) at the lumbar spine (LS) (MD 0.03 g/cm^2; 95% CI 0.01 to 0.05) and femoral neck (FN) (MD 0.04 g/cm^2; 95% CI 0.02 to 0.07). Significant differences were also revealed between WBE and LE in favor of LE for changes in LS BMD (MD -0.04 g/cm^2; 95% CI -0.06 to -0.02). However, there was no significant difference between WBE and LE for changes in FN BMD (MD -0.03 g/cm^2; 95% CI -0.08 to 0.01).

Conclusion. WBE may have benefits with respect to maintaining or improving bone health in postmenopausal women but less benefit when compared to LE. Further research is required on this topic.

Keywords. Water-based exercise, bone health, osteoporosis, preventive medicine, sports medicine

Introduction

Age-related bone loss is a major health concern. Loss of bone mass and micro-architectural deterioration of bone tissue are directly related to a decrease in bone strength and subsequently increased fracture risk, and ultimately lead to conditions clinically known as osteopenia and osteoporosis.[5,6] Osteoporotic fractures have particular importance in public health and are considered one of the most common causes of disability, as well as a major contributor to medical care costs around the world.[8] They are responsible for excess mortality, morbidity, chronic pain, reduction in quality of life, and admission to long-term care, significantly contributing to health and social care costs.[188] In Australia, it is estimated that osteopenia and osteoporosis affect approximately 7.5 million people, with one fragility fracture occurring every 3.6 minutes, which amounts to almost 400 per day.[9,10,82] The estimated total number of osteoporotic new fractures and re-fractures over the period 2012-2022 is predicted to be in excess of 1.6 million, with an estimated total direct and indirect cost to the Australian government, community, and individuals of AU$33.6 billion in this period.[11] Over this period, it is also projected that approximately 150,000 fractures could be prevented, with an annual saving ranging from AU$140 million to AU$187 million.[11] The residual lifetime risk of osteoporotic fractures for women aged 50 years old is estimated to be greater than 40% and represent 80% of all fractures in the population over this age.[189] For men aged 60 years-old, the residual lifetime fracture risk is estimated to be around 30%.[190]

The most common sites of osteoporotic fractures are the hips, spine and wrists. Hip fractures account for the majority of direct medical costs, and are also an important contributor to long-term disability, with almost 30% of older adults with a history of hip fracture not reaching their pre-fracture level of functioning one year following a fracture.[12] In addition to this, in the year following a hip fracture, there is a two-fold increase in mortality,[13] estimated to be around 30%, and it is higher among male patients (37.5%).[191] Vertebral osteoporotic fractures are often asymptomatic, therefore escaping clinical diagnosis; however, when compared to other types of fragility fractures, they are associated with higher comorbidity, higher incidence of hospitalization, and longer hospital stays.[14] In addition, they have been strongly related to subsequent fractures and mortality.[14,15] The residual lifetime risk of vertebral osteoporotic fractures is 8.6% for men aged 45 years and older, and 15.4% for women.[14] Distal radius fractures (occurring at the wrist) are more prevalent in women aged 45 to 65 years and the most common mechanism of these fractures is direct trauma.[48] Although fractures of the distal radius are considered to cause the least morbidity of all fragility fractures, these fractures are regarded as an important predictor of subsequent fractures and mortality.[16]

Even though the majority (60-80%) of the variation in bone strength is attributed to genetics,[24-27] bone is considered a dynamic tissue, exhibiting continuous remodeling activity. This remodeling process is mediated by osteoblasts, which are cells responsible for bone formation, and osteoclasts, which are cells responsible for bone resorption, causing bone loss. The remodeling process is capable of adapting and responding to various stimuli.[192-194] On this basis, it is estimated that lifestyle and environmental factors, such as nutrition, alcohol intake, smoking and skeletal loading, contribute to 20-40% of the variation in bone quality.[28] It is well known that prolonged periods of inactivity and unloading of the skeleton have a negative effect on bone mass, accelerating bone loss.[195] In addition, lean body mass and skeletal muscle mass are strongly related to bone mineral density.[30-32] It is also well documented that muscle contractions can increase loads on bones, generating stress and strain reactions in bone tissue,[35-37] and that dynamic loading has a more positive effect on bone tissue than static loading.[38]

Many efforts have been made to investigate non-pharmacological approaches to achieving an osteogenic (bone-producing) effect. It is well-known that the avoidance of tobacco and adequate serum levels of calcium and vitamin D are essential to bone health.[196-198] Physical activity has been shown to be an effective non-pharmacological approach to improve bone mass; however, not all types of exercise have been definitively shown to promote positive effects on bone metabolism.[18] In research to date, only impact weight bearing and high impact progressive resistance training activities have a strong level of evidence indicating a positive osteogenic effect.[19,20,124-127] However, it is well known that aging can also be associated with physical decline, including conditions such as joint limitations and chronic pain, and, therefore, high-impact exercise is not always indicated or appropriate for middle-aged and older adults.

Exercise executed in the water environment, often referred to as water-based exercise (WBE), presents lower risks of traumatic fracture, and the joints are exposed to less stress and impact (via reduced loading due to buoyancy), when compared to land-based exercise (LE), such as running, resistance training or strength training. Besides this, WBE has been highly recommended for older people, especially those with disability, due to the reduced pain[199] and increased security it can provide,[200] in addition to providing additional benefits for neuromuscular and functional fitness,[200] and cardiometabolic health.[201] Furthermore, considering the potential for a reduction in the prevalence of pain and injuries, the dropout rate among subjects participating in WBE may be lower than for some land-based activities. Finally, some older adults may simply enjoy WBE or wish to participate due to social reasons. In WBE, increased muscular demands are often necessary in order to overcome water resistance. For instance, Chevutschi et al.[202] demonstrated that walking in water at an umbilical level increased the activity of the erector spinae and activated the rectus femoris to levels near to or higher than walking on dry ground. Therefore, considering the muscle demands and the dynamic component of WBE, there might be adequate stimulus to generate osteogenic stress and strain reactions in bones.

However, the literature is inconsistent in its reports of the effects of WBE on bone health of middle-aged and older adults. Some observational studies that have investigated swimmers have reported that participants have similar, or sometimes lower, bone mineral density (BMD) when compared to sedentary controls, indicating swimming is associated with a similar or greater risk of bone deterioration and its consequences when compared to a sedentary lifestyle.[22,134,135] Velez et al.[22] reported that mature-aged males who restricted their physical activity to only swimming had a 10% higher prevalence of osteoporosis when compared to sedentary age- and gender-matched controls. Conversely, in a cross-sectional analysis, Balsamo et al.[23] concluded that aquatic exercise might be an effective non-pharmacological strategy to prevent bone loss in postmenopausal women. In addition to this, Gomez-Bruton et al.[136] conducted a systematic review analyzing the effects of swimming on bone tissue, analyzing 64 studies assessing children, adolescents, adults and elderly populations. It was reported that swimming had no negative influence on bone tissue, and might have benefits on bone health later in life.

To date, a consensus regarding the effects on bone health of exercise practiced in water has not been reached and a comprehensive literature search conducted by the authors identified no systematic review of the effects of water-based exercise other than swimming. Therefore, the effects of exercise undertaken in a water environment on bone health of middle-aged and older adults remain uncertain.

This systematic review and meta-analysis aimed to answer the following question: is water-based exercise effective in preventing age-related bone deterioration in middle-aged and older adults? The objective of the review was to assess the effect of water-based exercise interventions in preventing age-related bone deterioration when compared to a sedentary lifestyle or other forms of exercise.

Findings of this systematic review and meta-analysis are expected to contribute to the knowledge of health care professionals involved in this field with regard to the effectiveness of WBE, so that they can provide alternative recommendations regarding exercise types that can maintain or even enhance bone health and reduce the risk of fracture among their patients or clientele.

Methods

The review was conducted as a systematic review of relevant studies, incorporating both a critical narrative synthesis and meta-analysis. The design of this study was guided by consideration of the Cochrane Handbook for Systematic Reviews of Interventions[187] and the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement.[203] The methods and eligibility criteria for included studies were detailed in advance in a protocol registered at the international database of prospectively registered systematic reviews in health and social care, PROSPERO[204] (registration number CRD42015026685).

Eligibility criteria

To be included in the review, studies were required to be full-length research articles, published in academic journals or online (e-publication ahead of print), and no limits were set on language or date of publication. Only clinical trials (randomized or non-randomized controlled trials) and prospective observational studies were considered for inclusion, with no limits set of length of follow-up. Studies were also only considered if they analyzed human subjects, either male or female, and if participants were aged 45 years or older, asymptomatic and free living in the community. Participants in eligible studies could be healthy individuals, or individuals with diagnosed osteopenia or osteoporosis; however, studies involving participants with other known health disorders or restrictions on participation in physical activities were ineligible. In addition, studies included in the systematic review were required to have a type of water-based exercise or physical activity as the only intervention or exposure in at least one group, and a comparison group, such as people undertaking other types of exercise or sedentary controls. If any medication or supplements were given to one group, the study was only considered if the medication or supplement was also given to all other groups, using the same dosage. Eligible studies assessed bone mineral density (BMD) by dual-energy X-ray absorptiometry (DXA). The primary outcomes of interest in this review were: BMD and bone mineral content (BMC) measured by DXA, measured in at least one clinical site (lumbar spine, proximal femur, total hip or wrist); bone metabolism, measured by serum biomarkers; incidence rates of bone fractures; minor adverse events, including falls; and serious adverse events, including death. The secondary outcomes of interest were: muscle strength, flexibility, balance, and compliance with the intervention.

The following exclusion criteria were applied during study selection: publication types other than full-length journal articles, such as letters to the editor, conference abstracts, conference papers or book chapters; unpublished papers; studies using a descriptive or retrospective design; studies that did not evaluate human subjects; studies that did not evaluate middle-aged or older adults or that evaluated middle-aged or older adults together with other age groups without reporting the results separately; studies involving participants with medical disorders other than osteopenia or osteoporosis; studies that did not have water-based exercise as the sole intervention in at least one group; studies that did not have a comparison group; studies that did not have BMD as an outcome; and studies that did not measure BMD by DXA.

Search methods

To identify relevant studies, a multi-step search was conducted in October 2015, without any limits on publication date, in the following databases: PubMed/MEDLINE, the Cochrane Library, EMBASE, SPORTDiscus, CINAHL, ScienceDirect, Scopus, AUSPORT, and PEDro. In addition, hand searches of reference lists of included articles were also performed to identify additional studies and data that met criteria for inclusion. The search strategy was kept as broad as possible, with identification of articles achieved by use of specific text words, without using truncation, wildcards, or any other limits. Appendix II contains the complete search strategy used in PubMed/MEDLINE, as an example. Search strategies for other databases were equivalent but tailored to the nuances of the respective database, and are available upon request.

Data collection and analysis

Search results were imported into reference management software (EndNote),[205] where duplicate records were removed. Titles and abstracts were then screened, in order to exclude studies that were clearly ineligible. After initial screening, potentially eligible studies were retrieved for full-text eligibility assessment. The selection process applied to the full-text study reports was based upon the eligibility criteria discussed above, including: types of interventions; type of outcome measures; types of participants; and types of studies. Disagreements regarding assessed eligibility were resolved by consensus and reasons for exclusion of studies were documented. The results of the entire search, screening and selection process were recorded in a PRISMA diagram (Figure 9).[203]

Data were extracted and tabulated from all included papers using a standardized data extraction tool (The Cochrane Consumers & Communication

Review Group).[187] Data extracted from each paper included specific details of title, authors, source, year of publication, study design, participants, the intervention, the comparison groups, length of follow-up, and data related to the primary and secondary outcomes of interest for this review.

Risk of bias was assessed for each included study using the Cochrane Collaboration's Risk of Bias tool.[206] The following elements that potentially affect risk of bias were addressed: random sequence generation (selection bias); allocation concealment (selection bias); blinding of outcome assessment (detection bias); incomplete outcome data (attrition bias); selective reporting (reporting bias); and other sources of bias (comparability of treatment and control group at entry, appropriateness of duration of follow-up). The risk of bias in the included studies was narratively described, and then each item was assigned a judgment: "low", "high" or "unclear" risk of bias. Non-randomized controlled trials (quasi-experimental studies) and prospective observational studies were assessed and reported as being at a high risk of bias on the random sequence generation and allocation concealment items of the risk of bias tool.

Quantitative data was analyzed using the Cochrane software Review Manager (RevMan, version 5.3)[207] where outcomes were reported in at least two studies. Effect sizes for continuous outcomes were calculated as mean differences (MDs) or, if different scales had been used, as standardized mean differences (SMD), each with 95% confidence intervals, using a random-effects model. Missing data and attrition rates were assessed for each of the included studies, and were reported as the proportion of commencing participants included in the final analysis. Intention-to-treat analysis of reported data from each included study was applied when extracting data for the meta-analysis. That is, each participant was included in the group to which they were randomized, and all randomized participants were included in the analysis. Heterogeneity was assessed using the standard Chi-square test and I^2 value.[187] Heterogeneity was considered statistically significant at $p<0.10$. I^2 values between 0% and 30% were considered minimal, 30% to 50% moderate, 50% to 90% substantial, and greater than 90% considerable. The overall treatment or intervention effect was calculated for each outcome measure in each included study. The effect of treatment or intervention on each outcome measure was calculated as the difference between the intervention and control groups in the change in measured outcome from baseline to end of follow-up. For each outcome measure, variance was estimated based on the standard deviation (SD) of the mean difference between baseline and follow-up. When this value was not available and was not supplied by the respective study authors following a written request, we used the SD calculated from the p-value for the differences between means in the groups.[187] When the *p*-value was not available, we imputed the highest SD available from other studies included in the review.

Results

Search, screening and selection results

The search of electronic databases retrieved 12,271 records, with an additional 25 articles identified by searching references of potentially eligible articles. After removing duplicates, 7,823 articles remained to be screened by title and abstract, with 7,737 of these being excluded because they clearly did not meet eligibility criteria and 86 articles then remaining to be assessed for eligibility in full-text. From these full-text articles, 11 articles [137-141,208-213] that met eligibility criteria were identified and included in this review. Results from the search, screening and selection processes are summarised in a PRISMA Flow Diagram

(Figure 9).[203] Appendix III summarizes the characteristics of the 11 included studies.

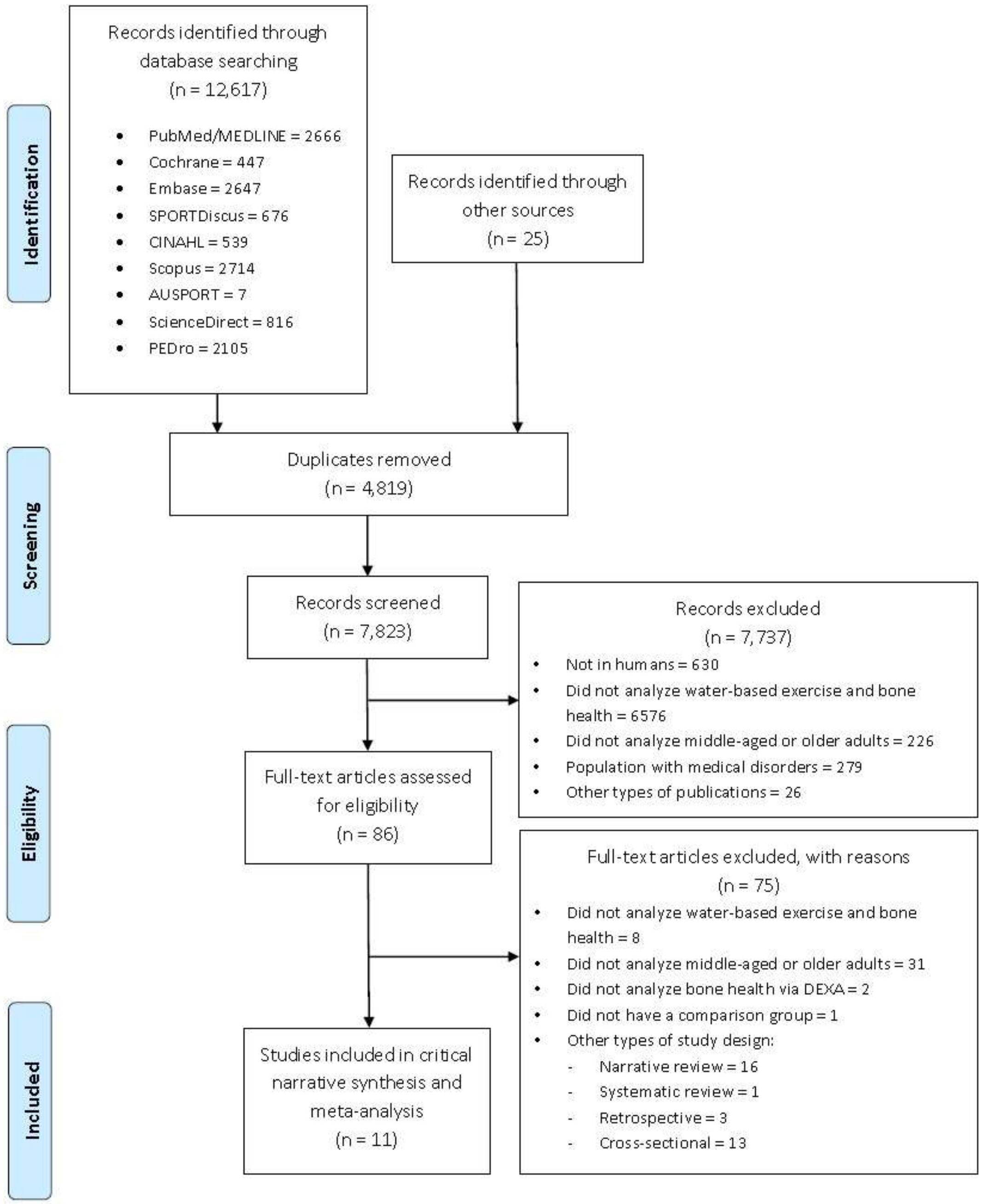


Figure 9: PRISMA Flow Diagram

Description of included studies

Of the 11 included studies, 5 were randomized controlled trials (RCTs) and 6 quasi-experiments (QE). A total of 629 participants were divided into 3 groups: participants who performed water-based exercise (WBE, n=344); participants who performed land-based exercise (LE, n=82), such as resistance training or strength training; and a sedentary control group (CG, n=203). All participants in the studies were postmenopausal women. Four studies reported that the participants were previously sedentary.[140,208,210,212] Regarding bone health, four studies recruited participants with low BMD (osteopenia or osteoporosis)[141,208,209,211] and one recruited women with normal BMD.[137] Groups from one study received alendronate sodium,[208] groups from two studies received a combination of alendronate sodium and vitamin D,[141,209] and groups from another two studies received a combination of vitamin D and calcium.[140,211] The studies were conducted in Brazil (n=5),[140,141,208-210] Japan (n=2),[138,213] Kosovo (n=1),[211] Israel (n=1),[137] Iran (n=1),[139] and Portugal (n=1).[212] Nine studies were published in English,[137-141,208,209,211,212] one article was translated from Portuguese,[210] and one from Japanese.[213] The length of the exercise interventions varied in the included studies: one study conducted the intervention for 24 months,[213] three for 12 months,[138,208,209] one for 10 months,[211] one for 8 months,[141] one for 7 months,[137] three for 6 months,[140,210,212] and one for 3 months.[139] The frequency and duration of the sessions also varied in the included studies, ranging from once a week to three times a week, and each session lasted from 35 to 75 minutes. The content of the training sessions for WBE groups was comprised of hydrogymnastics in 8 studies[137,139-141,208,209,211,212] and swimming in 2 studies.[210,213] One study combined both hydrogymnastics and swimming during the sessions.[138] Nine studies reported that exercise intensity was moderate to vigorous,[137-140,208-212] with the level of intensity determined by either heart rate or Borg scale. Four studies involved LE groups as comparison groups, and the LE training sessions consisted of resistance training,[208,210] strength training,[212] a mix of aerobics and resistance training,[211] and judo.[208] Eight studies compared WBE to a sedentary control group (CG).[137-141,208,209,213] One study included both a WBE and LE, as well as a CG.[208]

Risk of bias in included studies

The judgment about each risk of bias item for each included study is presented in Figure 10, and the percentages of all included studies deemed to be at low risk, unclear risk or high risk of bias based on each bias item are depicted in Figure 11.

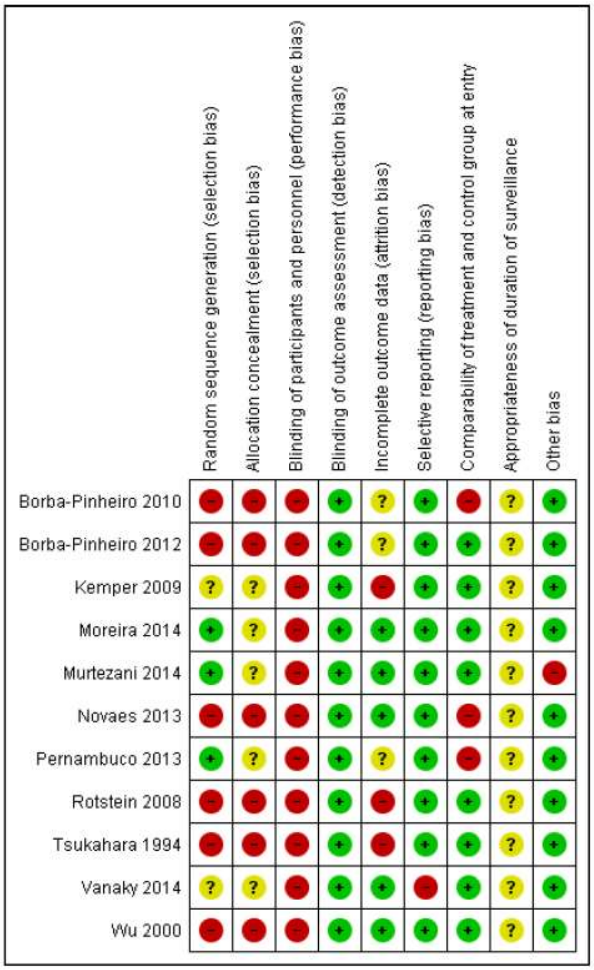


Figure 10: Risk of bias summary, by item and study

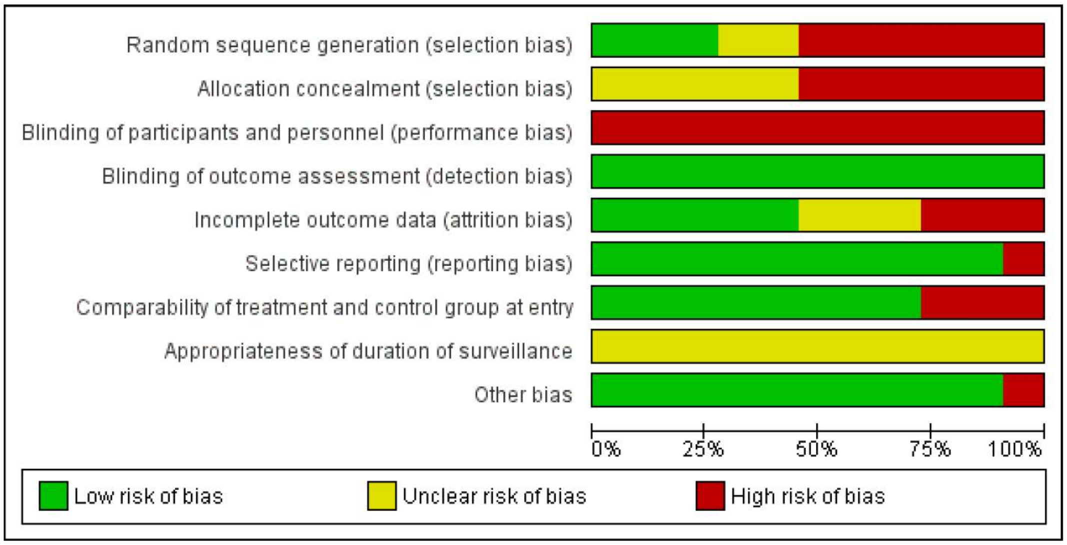


Figure 11: Risk of bias graph, by item

Random sequence generation and allocation concealment (selection bias)

All non-randomized studies (QE) were classified as "high risk" for both 'random sequence generation' and 'allocation concealment' items. Of the 5 RCTs included in the review, three reported adequate sequence generation and were classified as being at "low risk" of bias on this item.[140,141,211] The other two studies[139,210] reported that participants were randomized into groups; however methods of randomization were not described and they were classified as being at "unclear risk" of bias on this item. None of the included RCT described allocation concealment and so all were classified as being at "unclear risk" of bias for this item.

Blinding of participants and personnel (performance bias)

All studies were classified as being at "high risk" for performance bias, as none of the studies reported any attempt to blind participants and personnel (such as exercise instructors and researchers) to group allocations.

Blinding of outcome assessment (detection bias)

Considering the objective nature of the primary outcomes of interest, all studies were judged to be at "low risk" for detection bias.

Incomplete outcome data (attrition bias)

Five studies were considered to be at “low risk” of attrition bias as they either reported data for all participants or appropriately addressed incomplete outcome data.[139,140,211-213] Three studies were judged to be at “unclear risk”,[141,208,209] and three at “high risk”.[137,138,210] The study conducted by Kemper et al.[210] reported over 30% attrition for the LE group and approximately 13% for the WBE group, and those lost to follow-up were not accounted for in the final analysis. Rotstein et al.[137] reported 20% attrition in the WBE group, with no reasons mentioned, and again the analysis did not account for those lost to follow-up. In the study conducted by Tsukahara et al.,[138] there was an attrition rate of over 62% in the WBE group, with no reasons mentioned and no adjustment of the analysis to account for the losses.

Selective reporting (reporting bias)

In all but one study, the primary outcome was reasonably well reported. Vanaky et al.[139] reported their findings in a table that was poorly formatted and one of the reported results made no sense, and, therefore, this study was classified as presenting a “high risk” of reporting bias.

Comparability of groups at entry

Three studies[141,208,212] were judged to be at “high risk” of bias due to inadequate group comparability at entry. All other studies were judged to be at “low risk” of bias on this item.

Appropriateness of duration of follow-up

All studies were classified as being at “unclear risk” of bias stemming from lack of adequate duration of follow-up, as they only reported immediate post-intervention data.

Other bias

In the study conducted by Murtezani et al.,[211] the LE group engaged in longer and more frequent training sessions than the WBE group. In the discussion section of that paper, it was mentioned that the WBE group exercised twice a week for 30 minutes, whereas the LE group exercised three times per week for

55 minutes. Therefore, this study was judged to be at “high risk” of bias due to the different doses of exercise provided to the groups. All other studies appeared to be free from other obvious sources of bias.

Primary outcomes

Bone mineral density

All studies reported BMD for at least one clinical site. All studies reported BMD for the lumbar spine (LS), 8 reported BMD for the femoral neck (FN),[137,139,140,208-210,212,213] 4 reported BMD for the great trochanter (GT),[140,208,209,213] 2 reported BMD for Ward’s triangle (WT),[208,213] and 2 reported BMD for the total femur (TF).[140,141]

- LS BMD

LS BMD increased in participants performing WBE in 10 studies; however, this change was statistically significant in only one study.[139] Wu et al.[213] reported a non-significant decrease in LS BMD in the WBE group. All 8 studies that included a CG reported a non-significant decrease in LS BMD for this group.[137-141,208,209,213] Of the four studies reporting a LE group, three reported a statistically significant increase in LS BMD in this group.[208,211,212] Kemper et al.[210] reported a non-significant decrease. When comparing the results between groups, eight studies compared WBE and CG, and two described a statistically significant difference in change in LS BMD, in favor of the WBE group.[137,139] In the comparison between WBE and LE, two studies described a statistically significant difference between these exercise types in effects on LS BMD, in favor of the LE.[211,212] The results of a meta-analysis comparing the effects of WBE and CG on LS BMD are shown in Figure 12. The results revealed a significant difference between the groups in favor of WBE (MD 0.04 g/cm^2; 95% CI 0.02 to 0.07; p=0.0004; I^2=0%). In this meta-analysis, we excluded the study conducted by Vanaky et al., [139] due to its high risk of reporting bias, but a subsequent sensitivity analysis indicated that its inclusion in the analysis would not have affected the overall result anyway. For the comparison of the effects of WBE and LE interventions on LS BMD, results revealed a significant difference between the interventions in favor of LE (MD -0.04 g/cm^2; 95% CI -0.06 to -0.02; p<0.00001; I^2=0%), as shown in Figure 13.

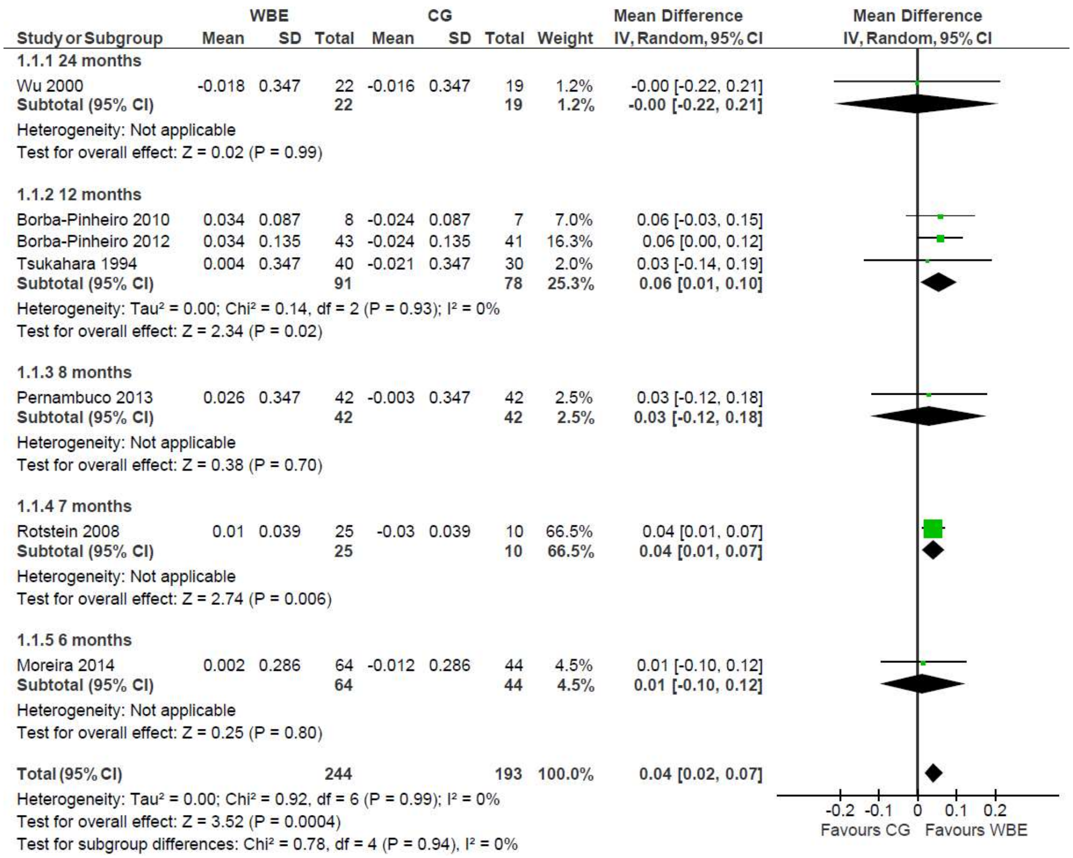


Figure 12: Forest plot of comparison WBE versus CG for changes in LS BMD (mean difference in g/cm^2)

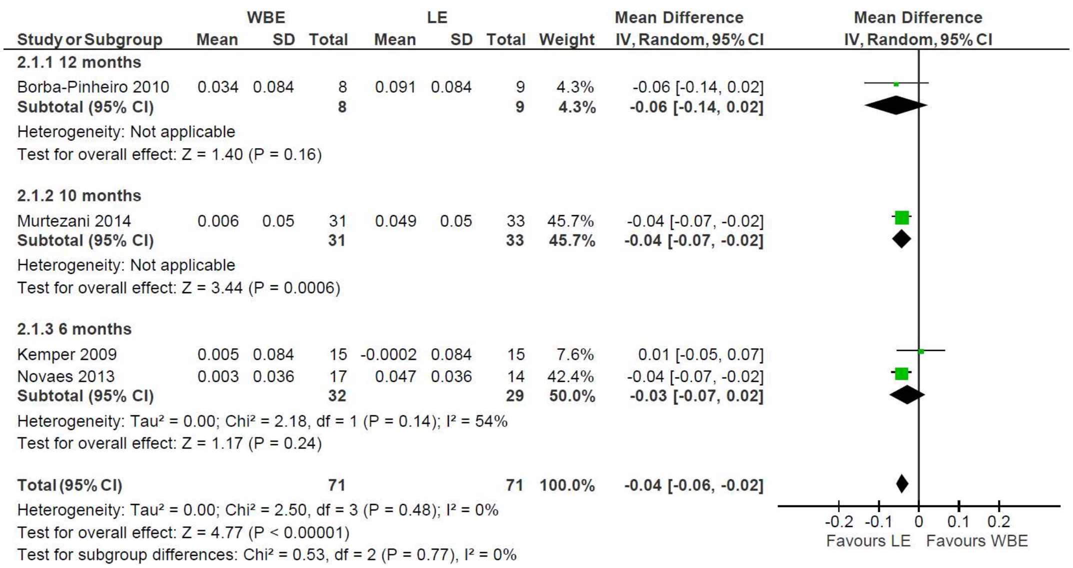


Figure 13: Forest plot of comparison WBE versus LE for changes in LS BMD (mean difference in g/cm^2)

- FN BMD

Of eight studies that examined FN BMD, five reported an increase in this value for the WBE group;[137,139,140,210,213] however only two studies reported a statistically significant change.[139,213] Two studies described a non-significant decrease in FN BMD in the WBE group,[208,209] and one study reported the same value at baseline and post-intervention time-points.[212] All six studies that assessed a CG reported a non-significant decrease in FN BMD in this sedentary group.[137,139,140,208,209,213] Of three studies that assessed FN BMD in the LE group, two studies described an increase,[208,212] which was statistically significant in one study,[212] and one study described a non-significant decrease.[210] When WBE was compared to CG, two studies reported statistically significant differences in FN BMD changes, in favor of WBE.[139,213] In the comparison between WBE and LE, two studies reported statistically significant differences in FN BMD changes, in favor of LE.[208,212] Figure 14 details the results of the meta-analysis comparing FN BMD changes in WBE and CG, showing that there was a statistically significant difference in favor of WBE (MD 0.03 g/cm^2; 95% CI 0.01 to 0.05; p=0.001; I^2=0%). Once again, the study by Vanaky et al.[139] was excluded in this meta-analysis, due to its high risk of reporting bias. In a subsequent sensitivity analysis, when this study was included, the results did not change, and heterogeneity was minimal (I^2=14%, *p*=0.32). In a further meta-analysis, there was no difference observed between WBE and LE interventions in changes in FN BMD (MD -0.03 g/cm^2; 95% CI -0.08 to 0.01; *p*=0.17; I^2=66%); however, heterogeneity was substantial (p = 0.05), as shown in Figure 15.

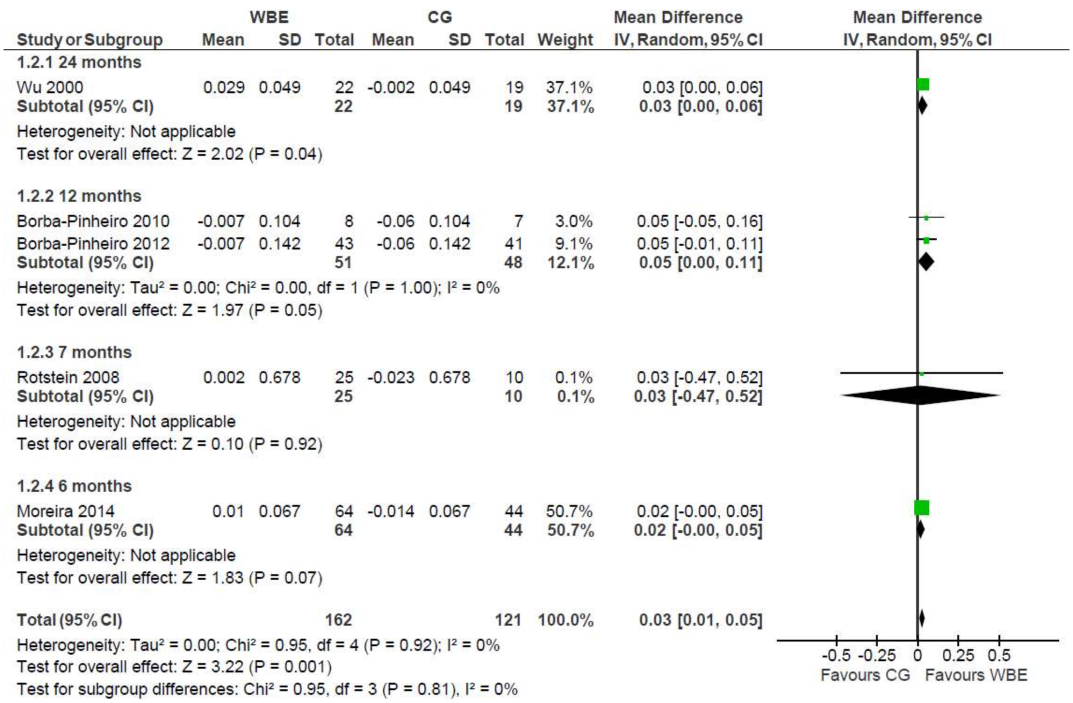


Figure 14: Forest plot of comparison WBE versus CG for changes in FN BMD (mean difference in g/cm^2)

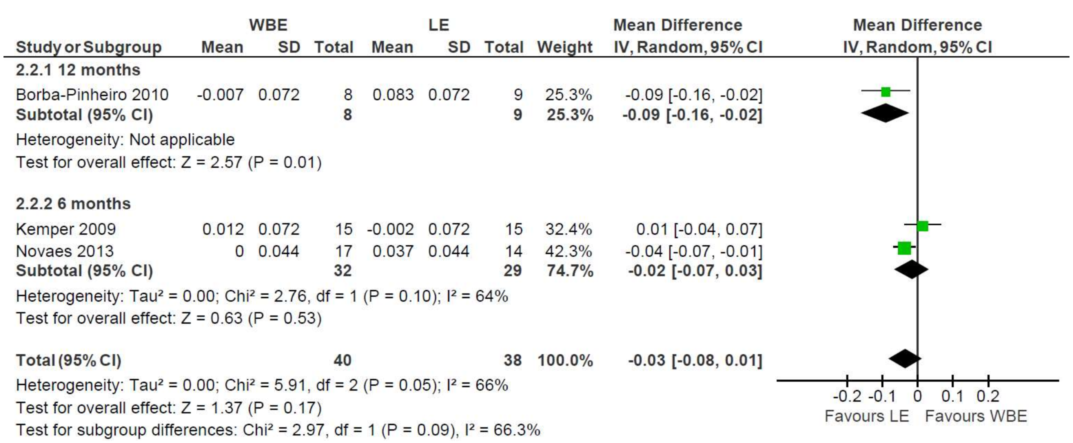


Figure 15: Forest plot of comparison WBE versus LE for changes in FN BMD (mean difference in g/cm^2)

- GT BMD

Of four studies that examined GT BMD, three reported an increase in GT BMD in the WBE group,[208,209,213] and the change was statistically significant in one study.[213] The fourth study did not report a change in the GT BMD value in the WBE group.[140] Four studies reported changes in GT BMD in the CG. Three reported a decrease,[140,208,209] which was statistically significant in one,[140] and one reported a non-significant increase.[213] Three studies reported a statistically significant difference between the WBE and CG groups in changes in GT BMD, in favor of WBE.[140,209,213] Only one study described a change in GT BMD in the LE group, reporting an increase, but no reference was provided to the statistical significance of the result[208] and when LE was compared to WBE with regard to changes in GT BMD, no statistical difference was found between the two groups. Meta-analysis was conducted to compare the effects of WBE and CG on GT BMD. The results revealed a statistically significant difference in favor of WBE (MD 0.04 g/cm^2; 95% CI 0.00 to 0.07; p=0.05; I^2=86%), as detailed in Figure 16. In order to address the considerable heterogeneity among studies in this particular meta-analysis, we conducted a sensitivity analysis to examine the impact of removing from the analysis the study conducted by Moreira et al.,[140] and the results were still in favor of WBE, with no heterogeneity then evident across the results (MD 0.05 g/cm^2; 95% CI 0.03 to 0.07; $p < 0.00001$; $I^2 = 0\%$), as shown in Figure 17.

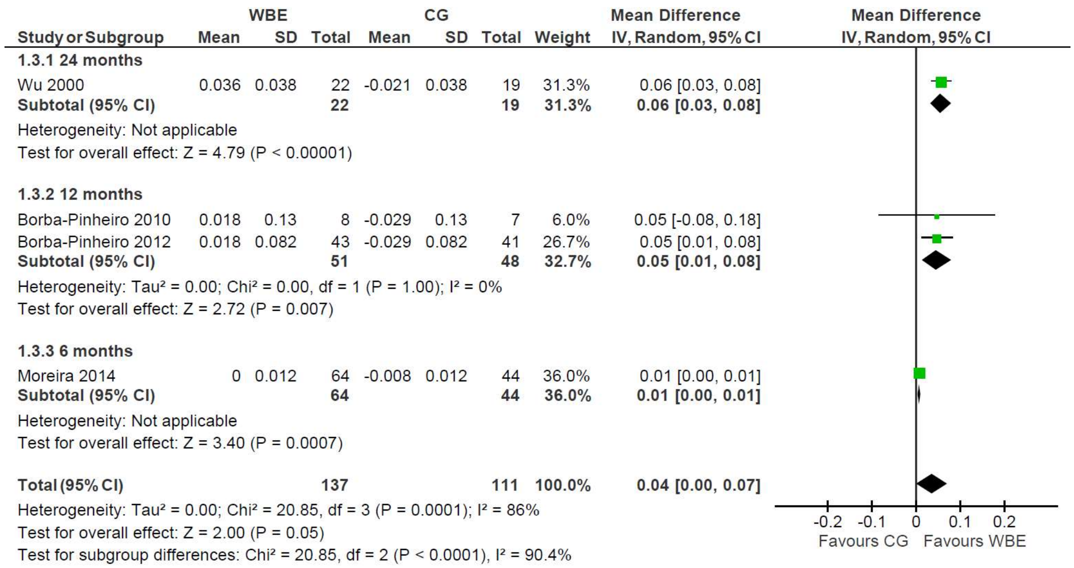


Figure 16: Forest plot of comparison WBE versus CG for changes in GT BMD (mean difference in g/cm^2)

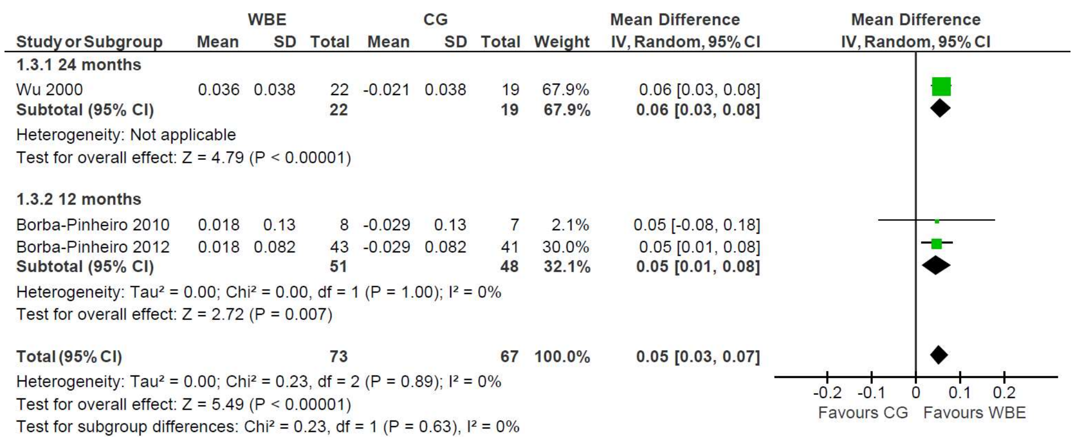


Figure 17: Forest plot of comparison WBE versus CG for changes in GT BMD (Moreira et al. excluded; mean difference in g/cm^2)

- WT BMD

Two studies assessed changes in WT BMD in the WBE group, and both reported a non-significant increase following WBE.[208,213] The same studies reported WT BMD results for a CG, and both described a non-significant decrease. A statistically significant difference between WBE and CG in their effects on WT BMD was observed, in favor of the WBE group, in the study conducted by Wu et al.[213] One of the studies also described a change in WT BMD for a LE group, reporting a non-significant increase in that group, and no differences between WBE and LE in their effects on WT BMD.[208] Meta-analysis revealed a significant difference between WBE and CG in their effects on WT BMD (MD 0.04 g/cm^2; 95% CI 0.00 to 0.08; *p*=0.04; I^2=0%), as presented in Figure 18.

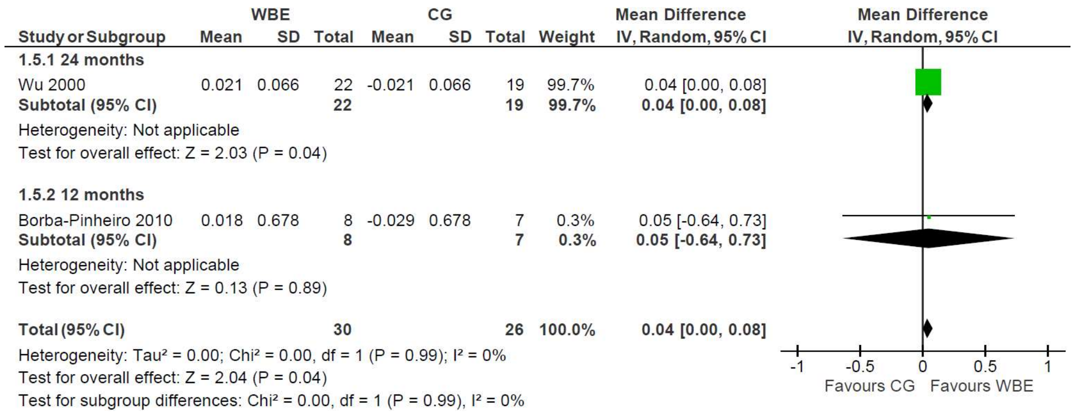


Figure 18: Forest plot of comparison WBE versus CG for changes in WT BMD (mean difference in g/cm^2)

- TF BMD

Two studies described changes in TF BMD in a WBE group and a CG, reporting non-significant increases in TF BMD following WBE, and non-significant decreases in TF BMD in the CG.[140,141] No significant differences were reported between these groups and no significant differences were found in the results of a meta-analysis (MD 0.02 g/cm^2; 95% CI -0.01 to 0.05; p = 0.15; I^2 = 0%), as detailed in Figure 19.

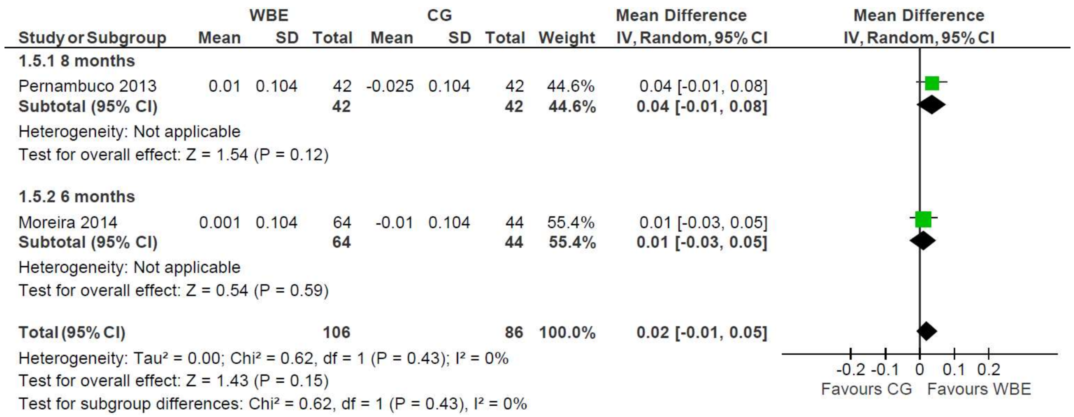


Figure 19: Forest plot of comparison WBE versus CG for changes in TF BMD (mean difference in g/cm^2)

Bone mineral content

Only one study reported BMC as an outcome measure.[137] Change in BMC was described for both LS and FN, in both WBE and CG. The authors reported a non-statistically significant increase in BMC at both of these sites in the WBE group and a non-statistically significant decrease in BMC at both sites in the CG group. In the comparison between these groups, both LS and FN BMC increased significantly more in the WBE group than in the CG.

Bone metabolism

Two studies included bone metabolism as an outcome measure,[140,141] and both compared the WBE results to results of a CG. Moreira et al.[140] analyzed the biomarker of bone formation, procollagen type 1 amino-terminal propeptide (P1NP), and the biomarker of bone resorption, carboxy-terminal cross-linking telopeptide of type 1 collagen (CTx), comparing the effects of WBE and CG on these biomarkers. The authors reported a mean increase in P1NP in both groups; however, the increase was statistically significant only in the WBE group. In the comparison between groups for P1NP, the effect on P1NP was significantly greater in the exercise group. The bone resorption biomarker CTx was observed to increase in both WBE and CG, but this increase reached statistical significance only in the CG, and no differences were found between these groups in their effects on CTx. In the study conducted by Pernambuco et al.,[141] the authors analyzed the biomarker of bone formation, osteocalcin. They reported a statistically significant increase in osteocalcin levels in the WBE group, and a non-significant decrease in the CG. The mean increase in osteocalcin levels following WBE was significantly greater than that in the CG. Meta-analysis revealed significant differences between WBE and CG in favor of WBE for changes in the biomarkers of bone formation (SMD 0.49; 95% CI 0.20 to 0.78; p=0.0008; I^2=0%), as presented in Figure 20.

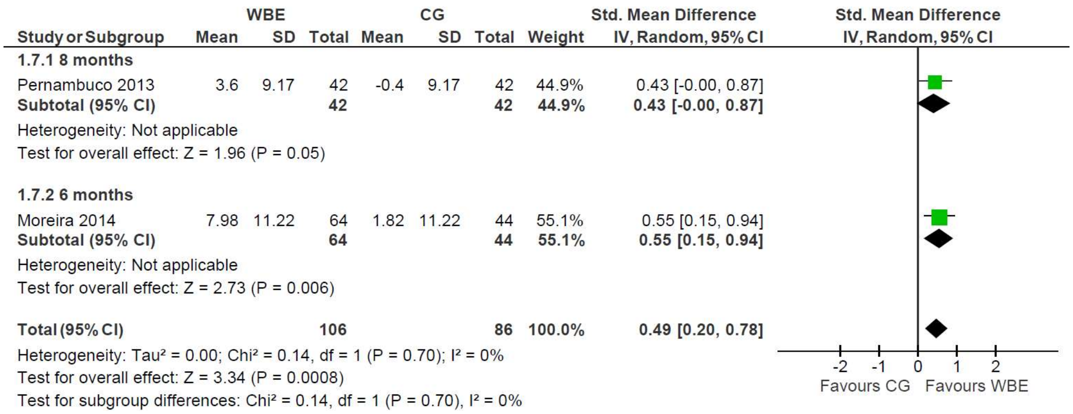


Figure 20: Forest plot of comparison WBE versus CG for changes in biomarkers of bone formation

Adverse events

Only three of the included studies reported information about adverse events. One of the studies reported that neither WBE group nor LE group participants experienced fractures or serious orthopedic problems.[211] In that study,[211] one individual allocated to the LE group withdrew due to injury; however, it is not clear if the injury was associated with the exercise intervention. In another study, it was reported that no injuries were experienced by the participants in the WBE group.[140] In the study conducted by Kemper et al.,[210] one individual was excluded due to chest pain during the WBE sessions. None of these three studies included fracture rate as an outcome, and no other study reported data regarding adverse events.

Secondary outcomes

Muscle strength

Two studies assessed muscle strength as an outcome.[211,213] Murtezani et al.[211] assessed right-hand grip strength (GS), and right quadriceps strength (QS), and compared WBE to LE. Both groups improved significantly in GS and QS; however, observed improvements following LE were significantly greater than those observed following WBE, for both outcomes. Wu et al.[213] reported QS changes, comparing the results of WBE to a CG. The WBE was associated with a statistically significant increase in QS whereas the CG was associated with a non-significant decrease, with no information provided about the level of statistical difference in this outcome between groups.

Flexibility

No studies provided data on changes in participant flexibility associated with WBE. One study reported flexibility as an outcome,[211] using the "bend reach performance test" (BRPT). This study compared the WBE group to a LE group, and the authors reported a statistically significant improvement in flexibility in the LE group; however, no results were reported for the WBE group.

Balance

Balance outcomes of participants were reported in two studies.[208,211] Both studies reported balance results for WBE and LE, and one also provided results for a CG.[208] Borba-Pinheiro et al.[208] assessed body balance using the Static Balance Test with Visual Control (SBTVC). Both WBE and LE groups improved in their balance ability following the respective type of exercise, and the CG group decreased in balance ability; however, no information regarding statistical significance of these changes in balance within groups was reported. When the balance results of the WBE group were compared to those for LE and CG, the differences in balance outcomes were not statistically significant. Murtezani et al.[211] assessed balance using the Berg Balance Scale (BBS) and reported positive changes in balance following WBE and LE, which reached statistical significance for the latter; however, no differences in balance outcomes were found between the WBE and LE groups. Meta-analysis was conducted to compare effects of WBE and LE on balance outcomes, and no statistically significant difference was found between the interventions (SMD -0.31; 95% CI -0.75 to 0.13; p=0.17; I^2=0%), as detailed in Figure 21.

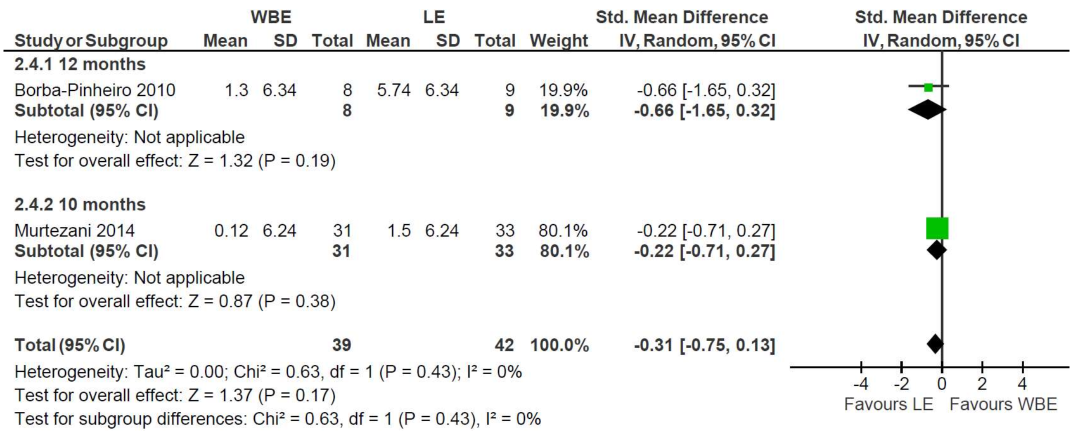


Figure 21: Forest plot of comparison WBE versus LE for changes in body balance

Compliance

Only two studies reported levels of exercise compliance for both WBE and LE groups.[210,212] Kemper et al.[210] described an attendance rate of more than 75% of the sessions in both WBE and LE groups, and Novaes et al.[212] described an attendance rate of more than 85% of the sessions in both groups.

Discussion

The main goal of the current systematic review was to determine the effects of WBE on bone health of middle-aged and older adults, and to compare these WBE effects to those observed in a sedentary CG or LE group. To the best of our knowledge, this is the first systematic review and meta-analysis addressing this topic. The main finding of the present systematic review supports the hypothesis that WBE may reduce age-related bone deterioration, as we identified statistically significant differences between WBE and CG in their effects on bone health, in favor of WBE. At the same time, the analyses also substantiate the belief that LE is more effective than WBE in promoting positive changes in the bone tissue.

The importance of this review lies in the fact that medical and health/fitness professionals should be able to provide recommendations regarding effective alternatives among exercise interventions, in order to keep the population physically active, preventing the bone loss associated with the aging process and subsequent increased risk of fracture. The findings of this review are consistent with findings of the systematic review conducted by Gomez-Bruton et al.,[136] which investigated the effects of swimming in different age groups, and revealed that WBE may have a positive impact on bone health in later adulthood. However, that review was limited to swimming, and the authors also concluded that the participants in the WBE had lower BMD than participants in land-based sports.

In the meta-analysis reported in this review comparing the effects of WBE to those of CG on LS BMD, the study conducted by Wu et al.[213] was the only study that reported bone loss in both WBE and CG groups at this clinical site (Figure 12). However, the decrease in BMD described in that study did not reach statistical significance within either group and no significant difference was evident between groups. As described in Appendix III, the type of WBE used in this QE[213] was swimming, and the intervention was conducted 1.5 times per week for 24 months, with no information included pertaining to the duration and intensity of the sessions. It is, therefore, impossible to ascertain the actual dose of swimming received by participants, which may have been too low to have an effect on bone metabolism. As can be seen from Figure 12, the study having the greatest weight in this particular meta-analysis was the study conducted by Rotstein et al.[137] The WBE in that QE was hydrogymnastics, conducted three times per week for seven months, in sessions of moderate to vigorous intensity, each lasting 60 minutes and involving participants who were post-menopausal women with normal BMD (Appendix III). Thus, it could be argued that interventions lasting longer than 6 months, with sessions of similar intensity and duration to those described by Rostein et al., [137] are likely to have positive effects on LS BMD. As shown in Figure 12, two RCTs were included in this particular meta-analysis focused on comparing the effects of WBE and CG on LS BMD,[140,141] and due to relative study weightings, these two RCTs contributed just 2.5% and 4.5% of the overall effect determined by the meta-analysis. The minor contribution of these RCTs is attributed to the relatively high SD associated with each. These values were obtained indirectly for both of these RCTs, as we could not obtain SD values from the reported results, and contact with authors was not successful. As we chose a conservative approach to estimate the SD, the real value might be lower than the one used in our analysis, and this would influence the impact of each study on the outcome of the meta-analysis, but not the overall observed effect. The same interpretation applies to the small contribution of the study conducted by Wu et al.[213] in this particular meta-analysis.

In the meta-analysis comparing the effects of WBE and LE on LS BMD, it is worth noting that all four studies included in the meta-analysis reported a non-significant increase in LS BMD in the WBE group, and three reported a statistically significant increase in LS BMD in the LE group (Figure 13). Surprisingly, the RCT conducted by Kemper et al.[210] reported a non-significant decrease in LS BMD in the LE group, which performed resistance training as the LE intervention, while swimming was the WBE intervention (Appendix III). The LE and WBE sessions were conducted three times per week, in moderate to vigorous sessions of 60 minutes, for 6 months. The dose of the swimming intervention may explain the difference between the results reported by Kemper et al.[210] and by Wu et al.[213] for swimming as a type of WBE – where Kemper et al.[210] observed a non-significant increase in LS BMD following the swimming intervention, Wu et al.,[213] who used a possibly much lower dose of swimming, observed a non-significant decrease. As depicted in Figure 13, two studies contributed with similar impact to this meta-analysis comparing effects of WBE and LE on LS BMD, with respective weightings of 45.7% and 42.4% in the meta-analysis, attributed to their relatively small SD for this outcome.[211,212] The first was a RCT conducted by Murtezani et al.[211] over 10 months, in which women with low BMD who were prescribed alendronate sodium and vitamin D were recruited (Appendix III). The authors reported statistically significant differences between the groups in the observed changes in LS BMD, in favor of LE; however, the differences reported might be explained by the fact that the exercise sessions were more frequent and lasted longer for individuals in the LE group, with this LE group therefore receiving a higher dose of exercise. The other study was conducted by Novaes et al.,[212] and was a QE conducted over 6 months, with exercise occurring three times per week, in sessions of 45 minutes of moderate to vigorous intensity (Appendix III). These authors also reported statistically significant differences between the WBE and LE groups in favor of LE. Of note in the comparison between WBE and LE with regard to their effects on LS BMD is that the study by Borba-Pinheiro et al.[208] is the only study in which the WBE intervention was conducted for more than 6 months, and the WBE involved sessions of moderate to vigorous intensity lasting 60 minutes. In that study, there was no statistically significant difference observed between the groups in changes in LS BMD, and this finding might be explained by the small sample size, which also influenced the study's minor contribution to the overall effect observed in the meta-analysis (Figure 13).

In the comparison between WBE and CG with regard to their effects on FN BMD, the study conducted by Moreira et al.[140] had a weighting of 50.7% in the meta-analysis, as a consequence of the small SD for this outcome measure (Figure 14). As detailed in Appendix III, this RCT was conducted over 6 months, analyzing the effects of hydrogymnastics on bone health of previously sedentary women who were prescribed calcium and vitamin D. The WBE sessions were of moderate to vigorous intensity, conducted three times a week and lasted between 50 to 60 minutes. This study did not detect a statistically significant difference between WBE and CG in their effects on FN BMD, and a possible explanation for this finding might be the fact that the intervention was limited to 6 months. In the comparison of the effects of WBE and LE on FN BMD, the results are limited by substantial heterogeneity, as shown in Figure 15. The QE conducted by Novaes et al.[212] contributed with a weighting of 42.3% to this meta-analysis, and the authors reported a statistically significant difference between the WBE and LE groups, in favor of the LE group. The exercise sessions of both groups lasted 45 minutes of moderate to vigorous intensity, three times per week, and follow-up was limited to 6 months (Appendix III). The RCT conducted by Kemper et al.[210] contributed to increase the heterogeneity in the assessment of the overall effect of WBE when compared to LE in this particular meta-analysis, as this study had contradictory results when compared to the other two studies included in the meta-analysis. The exercise sessions lasted 60 minutes of moderate to vigorous intensity, conducted three times per week for 6 months, and the authors reported a non-significant increase in FN BMD in the WBE group and a non-significant decrease in the LE group, with no differences found between the groups. Once again, these findings are consistent with the notion that WBE interventions conducted for a period of more than 6 months, in sessions of at least 60 minutes of moderate to high intensity and conducted three time per week, could possibly have a benefit to bone health. This hypothesis is also supported by the results reported for GT (Figure 16 and Figure 17), WT (Figure 18) and TF (Figure 19); however, it was only possible to compare WBE to CG in the analysis of these three clinical sites.

Interestingly, Moreira et al.[140] reported that both WBE and CG participants had a statistically significant increase in the biomarker of bone resorption CTx, although no differences were found between these groups. Those authors reported that levels of CTx typically increase in initial stages of the postmenopausal period, which was the case for the participants included in both groups. As shown in Figure 21, the RCT conducted by Murtezani et al.[211] contributed with a weighting of 80% in the meta-analysis comparing the effects on balance ability of WBE and LE, with this weighting being a consequence of the large sample size in that study. However, it is important to note that in that study the LE group engaged in more frequent and longer exercise sessions than the WBE group. For measures of muscle strength and flexibility, no meta-analyses were conducted due to a lack of studies reporting comparisons of these outcomes. Murtezani et al.[211] was the only study to report statistically significant differences between WBE and LE for both of these outcomes, each in favor of LE, but once again it is important to highlight the differences between the LE and WBE interventions used in this study, in terms of the frequency and duration of the exercise sessions, discussed above. The findings of the present review regarding effects of WBE on muscle strength and balance ability are in line with results of previous studies, which have demonstrated that individuals participating in WBE achieved a statistically significant improvement in both outcomes.[200,214-216] The studies conducted by Bergamin et al.[214] and Oh et al.[215]

also reported a statistically significant improvement in flexibility for participants in WBE.

Only three studies included in the current review reported information regarding adverse events; however, due to lack of adequate reporting, no definitive conclusions can be drawn in this regard.

One of the strengths of this review is the comprehensive search of published studies, which was not limited by language of publication. This allowed us to include in the analyses two studies published in languages other than English, eliminating language bias in the review. For the meta-analyses, we used the random-effects model, as this enabled the researchers to estimate the mean effect across a range of studies in a manner that meant none of the individual studies could overly influence the overall estimate of effect. However, limitations should be highlighted. The generally low quality of available studies and the inclusion of QE in the meta-analyses means that the results should be interpreted with caution. Another limitation is that none of the included studies reported the standard deviation (SD) for the mean change in BMD. This value is necessary in order to conduct meta-analyses of the results and so this value was estimated for each group. This estimate was derived for each study by either calculating the SD based on the reported *p*-value, or by imputing the largest SD for that specific outcome that was reported in other studies. This approach was decided in order to achieve more conservative results but may have therefore also limited some of the effect sizes estimated in the meta-analyses. No study investigating a male population was found or included in this review, and so further research involving male participants is needed. It should also be noted that this review was purposely limited to investigating effects of WBE on bone health of middle-aged and older adults and so the results should not be extrapolated to younger populations.

Conclusion

The results of this study corroborate the widely-held belief that WBE is not as effective as LE for enhancing bone health but they also indicate that, when the exercise dose is sufficient, WBE is better for bone health than a sedentary lifestyle in middle-aged and older adults. In order to increase exercise participation in middle-aged and older adults, it may be important to focus on alternative modes of exercise that are both suitable and feasible for this population, and which take into account possible clinical limitations of the individual and personal preferences. The results of the current meta-analyses indicate that an adequate dose of WBE may be a useful alternative to LE, as it appears to decrease the rate of age-related bone loss in post-menopausal women. Moreover, it can increase BMD in this population, and it was demonstrated to have positive impacts on both bone metabolism and muscle strength.

There is currently not sufficient evidence to form a basis for recommending any specific WBE intervention when aiming to improve bone health, however, the results of this review suggest that WBE of higher intensity, frequency and session duration, sustained over many months, is likely to be most beneficial. Importantly, the findings of this review cannot be extrapolated to a male population since all participants in included studies were post-menopausal women, and they should not be extrapolated to younger populations, since the review was designed to focus only on middle-aged and older participants.

Further well-designed randomized controlled trials, including both males and females, should be undertaken to investigate the effects of WBE on bone health of middle-aged and older adults and to compare the effects of different types of WBE. Based on our findings, it appears future interventions should be designed to last at least 12 months, and that the WBE sessions should be of moderate to vigorous intensity and at least 60 minutes in duration, occurring at least three times a week. With respect to BMD results, future research should adequately report standard deviations for the mean change within groups in this outcome measure, along with its p-value, in order to enable correct interpretation of the effect size of the results.

Chapter 4: Reliability and precision of dual-energy x-ray absorptiometry in assessing body composition and bone mineral density.

Preface

As highlighted in Chapter 2, the correct positioning of the patient during a dual-energy x-ray absorptiometry (DXA) scan is crucial in order to acquire adequate images, ensuring correct interpretation of the results obtained.

Therefore, prior to assessing the bone mineral density of middle-aged and older adults via DXA, there was a need to review the literature around positioning protocols for the scan. Additionally, to determine precision of the results, a reliability and precision study was also required. Consequently, under the guidance and supervision of the author of this thesis, two Doctor of Physiotherapy students assisted with conducting studies designed to determine the reliability and precision of DXA scan. These were necessary precursors to conducting the cross-sectional study that follows in Chapter 5.

Thus, the present chapter is comprised of four different parts. The first is a systematic review of the literature to identify and assess methods and protocols used for assessing body composition. It was published in the Journal of Science and Medicine in Sport. The second section investigates the level of agreement between the two most used protocols identified through the literature review, to determine whether one was superior to another. This section was published in the PeerJ journal. The third section details the reliability and precision of the positioning protocol chosen to be used in the study presented in Chapter 5. This section was published in International Journal of Sport Nutrition and Exercise Metabolism. Lastly, the fourth section investigates the reliability of the most acceptable protocol for assessing bone mineral density via DXA scan.

All three manuscripts presented in this chapter were planned, supervised and guided by the author of this thesis, and a copy of the manuscripts are found in Appendices IV, V, and VI. Additionally, all DXA scans were performed by the author of this thesis (VS). The published papers are as follows:

Shiel F, Persson C, Furness J, ***Simas V****, Pope R, Climstein M, Hing W, Schram B. Dual energy X-ray absorptiometry positioning protocols in assessing body composition: A systematic review of the literature. J Sci Med Sport. 2018 Oct;21(10):1038-1044. doi: 10.1016/j.jsams.2018.03.005.* Reproduced with permission from Elsevier.

Shiel F, Persson C, ***Simas V****, Furness J, Climstein M, Schram B. Investigating the level of agreement of two positioning protocols when using dual energy X-ray absorptiometry in the assessment of body composition. PeerJ. 2017 Oct 16;5:e3880. doi: 10.7717/peerj.3880.* This is an Open Access article reproduced under the permission of the Creative Commons Attribution Non-Commercial (CC BY-NC 4.0) license.

Shiel F, Persson C, ***Simas V****, Furness J, Climstein M, Pope R, Schram B. Reliability and Precision of the Nana Protocol to Assess Body Composition Using Dual Energy X-Ray Absorptiometry. Int J Sport Nutr Exerc Metab. 2018 Jan 1;28(1):19-25. doi: 10.1123/ijsnem.2017-0174.* Reproduced with permission from Human Kinetics, Inc.

4.1 Dual energy X-ray absorptiometry positioning protocols in assessing body composition: A systematic review of the literature.

Abstract

Objectives: To systematically identify and assess methods and protocols used to reduce technical and biological errors in published studies that have investigated reliability of dual energy X-ray absorptiometry (DXA) for assessing body composition.

Design: Systematic Review

Methods: Systematic searches of five databases were used to identify studies of DXA reliability. Two independent reviewers used a modified critical appraisal tool to assess their methodological quality. Data was extracted and synthesized using a level of evidence approach. Further analysis was then undertaken of methods used to decrease DXA errors (technical and biological) and so enhance DXA reliability.

Results: Twelve studies met eligibility criteria. Four of the articles were deemed high quality. Quality articles considered biological and technical errors when preparing participants for DXA scanning. The Nana positioning protocol was assessed to have a strong level of evidence. The studies providing this evidence indicated very high test-retest reliability (ICC 0.90-1.00 or less than 1% change in mean) of the Nana positioning protocol. The National Health and Nutrition Examination Survey (NHANES) positioning protocol was deemed to have a moderate level of evidence due to lack of high quality studies. However, the available studies found the NHANES positioning protocol had very high test-retest reliability. Evidence is limited and reported reliability has varied in papers where no specific positioning protocol was used or reported.

Conclusion: Due to the strong level of evidence of excellent test-retest reliability that supports use of the Nana positioning protocol, it is recommended as the first choice for clinicians when using DXA to assess body composition.

Keywords: Test-Retest Reliability, body fat; DXA; lean mass, positioning

Introduction

Dual-energy X-ray absorptiometry (DXA) is a widely accepted method for the assessment of tissue composition.[217] Low bone mineral density (BMD) and associated conditions such as osteoporosis and osteopenia are a significant health problem that costs over eight hundred and thirty million dollars annually and osteoporosis is a significant cause of morbidity and mortality.[11,218] The need to accurately and effectively measure BMD in conditions such as osteoporosis lead to the development of the DXA scanner.[220] Now, DXA is considered the gold standard for the assessment of BMD and associated fracture risk.[221] However, DXA is also a valuable clinical tool in the assessment of body composition (BC), due particularly to its ability to assess body segments for lean mass (LM) and fat mass (FM) distributions.[222] The absorption rates of the two different energy levels (40 and 70 KeV) within DXA coupled with the distinctive elements of bone, fat, and lean tissue enable clear imaging of each tissue type and subsequent analysis.[222] Therefore, DXA can be used for assessing segmental body composition (SBC) and is currently used in clinical, sporting and research settings. The data gathered from SBC scans have improved knowledge of malnutrition, growth, aging, obesity and the efficacy of medical treatment interventions (surgical, pharmacological, dietary and exercise).[223] When used in the sport setting, DXA has enabled the tracking of players overall tissue composition as it has been found that individuals with the lowest start of season BMD and LM values have a greater occurrence of bone-related injuries.[224] Nevertheless, the reliability of the DXA scanner is fundamental to the validity of all clinical investigations and research studies that use it to assess BC.

In order to draw valid and reliable conclusions from DXA scan results, the concept of error must be considered. The literature describes biological and technical error as sources for reduced test-retest reliability of the DXA scanner.[225] The International Society for Clinical Densitometry (ISCD) recommends precise measures during preparation of the participant (fasting state, clothing, time of day, physical activity and empty bladder) and consistent positioning.[225] It has been shown that sources of biological error in DXA results include hydration,[217,225,226] stomach content and food consumption,[217,225,226] time of day of scanning[225] and physical activity[225,226]; furthermore, sources of technical error include artifacts such as clothing,[225] number of operators used to complete scans[227] and position of participant.[217,225,228,229]

The influence of positioning of the participant in the DXA scanner can be analyzed further by considering three identifiable positioning protocols. The first of these is the National Centre for Health Statistics, National Health and Nutrition Examination Survey (NHANES) Body Composition[228] positioning protocol, which the International Society International Society for Clinical Densitometry recommends,[225] requires individuals to assume a supine position with feet secured together with a strap, and the palms of the hands flat on the scanning table and not touching the lateral aspect of the body. It should be noted that the Australian and New Zealand Bone Mineral Society (ANZBMS)[85] employs the same body position. The second key protocol, the Nana positioning protocol,[217] requires individuals to be in a supine position while placing hands in a neutral position alongside the body and feet in radio-opaque positioning pads. The third approach evident in the literature involves no specific positioning protocol being reported at all.

The study of Kerr et al.[229] is to date the only study that has attempted to compare the reliability of different DXA positioning protocols for assessing BC, to identify which protocol was the most valid and reliable to use in clinical practice. They reported the Nana positioning protocol was the preferred positioning protocol based upon participant comfort when assessing BC with DXA. In their study, the positioning protocols were modified versions of the standard Nana and NHANES protocols. In contrast, most other studies that have assessed the test-retest reliability of their DXA scanner have not compared the reliability of different positioning protocols.

Therefore, the aim of this literature review was to systematically identify and assess methods and protocols used in previously published research that has investigated reliability of DXA, when it is employed to assess BC, to reduce technical and biological errors.

Methods

A search of academic databases was undertaken on 26.09.2016 with the intention of finding studies that have assessed the test-retest reliability of positioning protocols used when assessing BC by DXA. The search was limited to studies conducted over the recent 10-year period (01.09.2006 to 26.09.2016) to maintain currency. The search was limited to only articles that included the term 'DXA' or a synonym for DXA in the title, as searches not limited in this way provided an excessive number of irrelevant articles. Details of the search strategy and key terms can be found in Figure 22.

Two reviewers (F.S and C.P) assessed the identified literature and removed duplicates. Titles and abstracts were initially screened and articles removed if eligibility criteria were not met. Inclusion criteria included: (1) studies conducted on living human participants, (2) studies of an adult population, and (3) studies primarily investigating reliability of DXA scanning protocols. Exclusion criteria were: (1) non-healthy subjects (eg subjects with: osteoporosis, current fractures, hemiarthroplasty and total joint replacements, rheumatoid or osteoarthritis, current cardiac or pulmonary conditions, or diabetes) (2) studies published prior to September 2006, (3) studies comparing MRI or CT to DXA, and (4) studies not available in English. In the event that insufficient details were provided in the titles and abstracts of articles to allow determination of eligibility, review of full texts was completed, with reference to eligibility criteria and ineligible articles were removed. The remaining articles were included in this literature review. A PRISMA flow diagram (Figure 22) was used to document the study screening and article selection processes.[231]

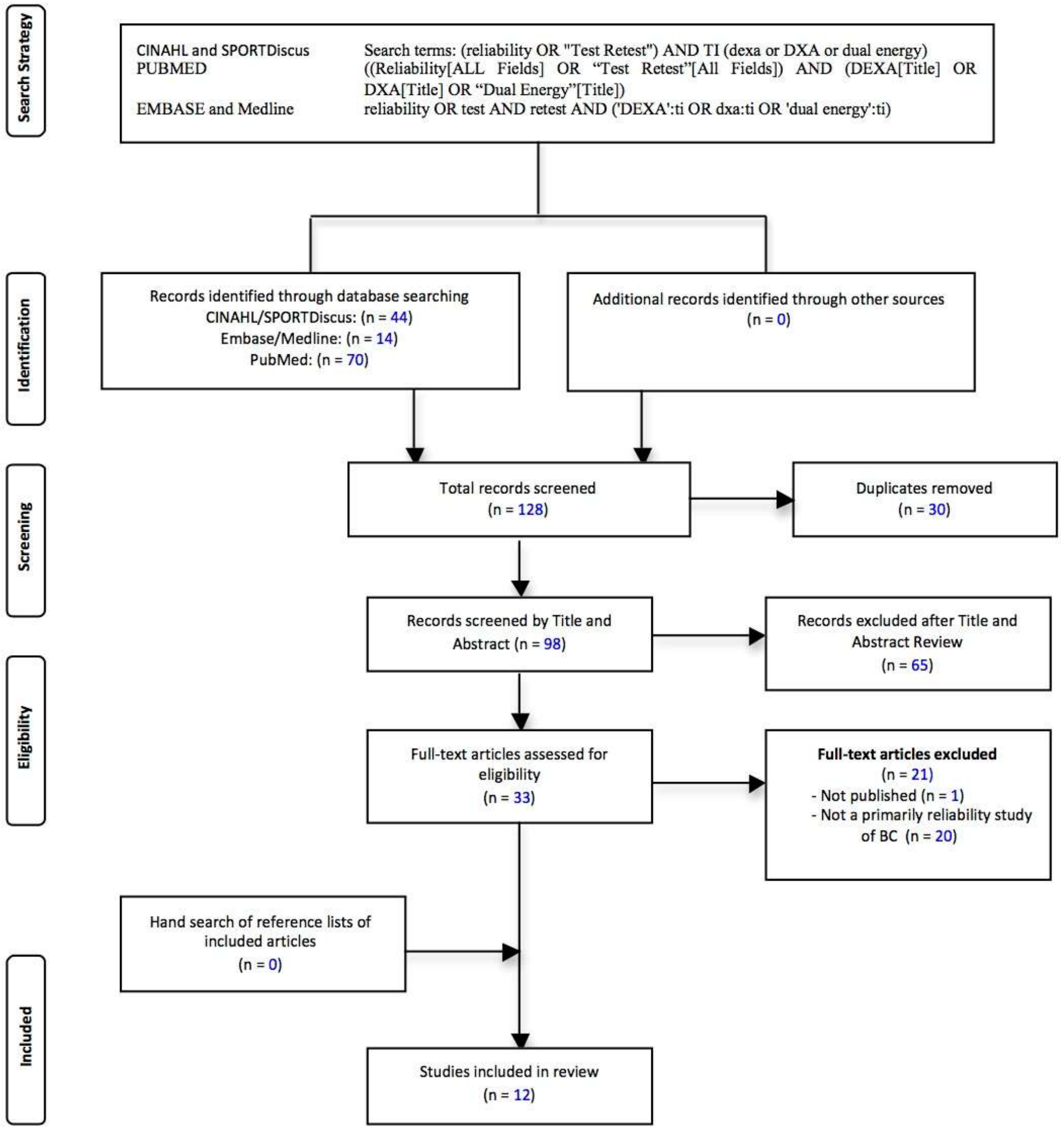


Figure 22: PRISMA flow diagram of literature search strategy

In order to critically appraise the included DXA reliability full text articles, a modified version of the reliability and validity critical appraisal tool (CAT) described by Brink and Louw[232] was utilized, with items designed to appraise studies of validity removed, since the focus of this review was studies of reliability. The thirteen-item CAT was reduced to ten items by removing all items that did not relate to reliability, and was applied by two independent reviewers (F.S and C.P) in order to assess the methodological quality of each study. When both assessors were not in agreement, a consensus was reached by discussion to determine the item's final CAT results. The CAT did not originally include a scoring system; therefore for the purpose of this literature review, a scoring system was implemented to aid in a quality and reliable analysis, similar to previously published reviews.[233-236] Studies of higher quality scored $\geq$60% in the modified CAT, and were rated higher due to their superior methodology.[237]

To receive a positive appraisal regarding the appropriateness of statistics in the CAT, each study reporting reliability must have reported an intraclass correlation coefficient (ICC) accompanied with confidence intervals (CI) or a percentage change in mean accompanied with typical error of measurement.[238] If the only basis for inclusion of a study was that it reported a percentage change in mean, then the calculation of the percentage change in mean must have complied with the guidance of previous work and have included a typical error of measurement in calculations.[239,240] Pearson correlation coefficients were not deemed suitable as measures of reliability; as they did not take into account the consistency of measurements from test to retest and the change in average measurements of participants.[241] The ICC results of the studies that included ICC values were interpreted as indicators of reliability as follows: ICC of 0.00–0.29, very low reliability; 0.30–0.49, low reliability; 0.50–0.69, moderate reliability; 0.70–0.89, high reliability; and 0.90–1.00, very high reliability.[242] An assessment of high or very high reliability depended primarily upon a reported high or very high ICC (above 0.70) or a low reported percentage change in the mean. The reported change in mean needed to be lower than the minimum clinically significant difference ascertained through consultation with practitioners. This ensured that any systematic error in repeated measurements observed during reliability testing was not sufficiently large to obscure clinically important changes or differences in the respective outcome measure – another indication of reliability.

Following critical appraisal, data were extracted from the included full text articles and tabulated to identify participant characteristics, the extent of standardization employed to minimize technical and biological errors, the types of statistical analyses undertaken, and reported results of each study.

A meta-analysis was not undertaken due to the diversity of the methods examined and the statistical analyses employed. Rather, a critical narrative approach was applied to synthesize and analyze the data obtained from the included studies, using a level of evidence approach.[243] Each positioning protocol identified from included studies was assigned a ‘strong’, ‘moderate’, or ‘limited’ level of evidence, based upon the number of studies that had examined its reliability and the quality of these studies. In order to be rated as having a strong level of evidence, a protocol required consistent findings from >3 high quality studies; to be assessed as having a moderate level of evidence, a protocol required consistent findings from at least 1 high quality study and 1 or more low quality studies; and to be assessed as having a limited level evidence, a protocol required consistent findings from >1 low quality study or only having 1 study available.

The use of standardization of methods of measurement to control sources of biological and technical error was assessed based upon the recommendations from the International Society of Clinical Densitometry.[225] Studies that reported having used the appropriate controls were considered more robust. As such the study must have included descriptions indicating how technical (clothing, positioning protocol) and biological (hydration, fasting state, time of day of scanning and physical activity) sources of error were controlled.

Results

The results of the electronic database literature search and subsequent screening and selection process are depicted in Figure 22. The search yielded 128 results. After titles and abstracts were screened and clearly-ineligible studies and duplicates removed,[231] the full texts of 33 articles were obtained and further assessed based upon the inclusion/exclusion criteria. Twelve articles were subsequently included in this review.

A total of 724 participants were involved in the twelve (12) studies included in this review. Three hundred and twenty seven (327) were males; two hundred and twenty eight (228) were females; and two studies[244,245] involved one hundred and forty nine (149) participants but did not categorize participants’ based on gender. The reported range of participant mean ages was 22.7 - 71.5 years, with the mean being 39.4 years. Nine studies reported mean mass, with the range of mean masses being 68.0 - 98.1 kgs and the mean being 77.1 kgs; similarly, the range of reported heights was 168.0 – 186.0 cm, with the mean being 174.8 cm. Three[246-248] studies reported BMI instead of reporting mass and height and in those studies BMI ranged from 26.5 to 27.1 kg/m^2, with the mean being 26.8 kg/m^2.

Of the twelve included studies, only four of the studies were assessed as high quality using the CAT. Nine[217,226,229,244,246,247,249-251] of the twelve studies reported statistics that were deemed appropriate (percentage change in mean accompanied by typical error or ICC). The three studies[245,248,252] that failed to report appropriate statistics were deemed to be of insufficient quality to warrant a high rating from the CAT[237]. Seven[217,226,229,244,248-250] of the twelve included studies used methods that were assessed as being reproducible, but only four[217,226,229,249] of these were rated as high quality studies. A detailed description of all articles assessed using the CAT can be found in Table 7.

Table 7: Critical appraisal tool

Article	Subjects	Characteristics	Scanner qualified	Rater		Random order	Test retest		Can reproduce protocol	Withdrawals explained	Statistics reported appropriate	High quality?
				Intra	Inter		Time period	Period valid				
Bilsborough et al.	47 47M	Yes 22.7 ± 3.0 years 84.4 ± 5.62 kg, 186 ± 5 cm	Yes	NA	No	Yes	Yes Immediate	Yes	Yes	No	Yes ICC %CV	Yes
Colyer et al.	53 34M 19F	Yes 23.0 ± 4.0 years 79.9 ± 18.9 kg, 178 ± 10 cm	No	No	No	No	Yes 2 days	Yes	Yes	No	Yes ICC %CL	No
Covey et al.	42 1M 41F	Yes 50.4 ± 9.9 years 27.1 ± 6.1 kg/m^2	Yes	NA	No	No	Yes 1 day	Yes	No	No	Yes % Difference Limit of agreement	No
Covey et al.	39 39F	Yes 56.6 ± 9.6 years 26.8 ± 5.5 kg/m^2	Yes	NA	No	No	Yes 7–14 days	Yes	No	No	Yes % Difference Limit of agreement	No
Hurst et al.	166 81M 85F	Yes 38.9 (36.9–40.9) years 75.5 kg, 171 cm	No	NA	No	No	Yes Max 5 days	Yes	No	No	Yes % Change	No
Kerr et al.	30 14M 16F	Yes 36 ± 11.5 years 71.0 ± 7.1 kg, 173.5 ± 0.5 cm	Yes	NA	No	Yes	Yes Immediate	Yes	Yes	No	Yes % Change %CV	Yes
Lohman et al.	30 30M	Yes 45.2 (22.0–61.0) years 26.5 (17.8–33.9) kg/m^2	Yes	NA	No	No	Yes Immediate	Yes	Yes	No	No Pearson r value	No
Moon et al.	82 44M 38F	Yes 71.5 ± 5.3 years 71.4 ± 8.1 kg, 168.3 ± 5.3 cm	No	NA	No	Yes	Yes 12 Weeks	No	No	No	No Pearson r value	No
Nana et al.	31 16M 15F	Yes 27.0 ± 5.0 years 68 ± 7.5 kg, 172.5 ± 6.0 cm	Yes	NA	No	No	Yes Immediate	Yes	Yes	No	Yes % Change %CV	Yes
Nana et al.	55 41M 14F	Yes 27.7 ± 6.3 years 75.5 ± 7.9 kg, 176.4 ± 5.7 cm	Yes	NA	No	No	Yes Immediate	Yes	Yes	No	Yes % Change %CV	Yes
Smith-Ryan et al.	127	Yes 35.8 ± 9.4 years 98.1 ± 20.9 kg, 176.3 ± 9.2 cm	No	NA	No	No	Yes 7–10 days	Yes	Yes	No	Yes ICC %CV	No
Wilson et al.	22	Yes 37.8 ± 15.5 years 70.1 ± 14.8 kg, 172.0 ± 11.4 cm	Yes	NA	No	No	No	Yes	No	No	No Root square mean %CV	No

M: male, F: female, cm: centimetres, kg: kilograms, kg/m^2 kilograms per square metre, % Change: percentage change in mean, ICC: intraclass correlation coefficient, %CV: percentage of coefficient of variation, CL%: confidence limit percentage, SEE: standard error estimation.

The extent of standardization of procedures to limit biological and technical errors varied significantly between the studies. Only three [217,226,229] of the twelve included studies reported all of the desirable information on the following standardized procedures: positioning protocol, clothing worn, physical activity completed by participant on day of scan, participant food intake on day of scan, participant hydration status and the time of day that the scanning took place. A further eight studies[217,226,229,244,245,249-251] reported the clothing worn, whilst seven studies[217,226,229,249-252] checked hydration status and six studies[217,226,229,244,251,252] reported assessing participants in a fasted state. Less than half of the studies[226,229,244,251] reported scanning participants in a rested state. The time of the scan was only reported in four[217,226,229,244] of the twelve studies.

The 12 included studies reported a variety of statistical representations of reliability, including percentage change in mean with the typical error of measurement, or ICC with coefficient of variation (CV). Of the studies that reported ICC, all found the DXA results to have very high test-retest reliability.[242] All studies that used a percentage change in mean as the test-retest reliability measure reported a change of less than one percent, and all percentage changes in mean were less than the minimum clinically significant difference. A summary of the reliability results from the included studies can be found in Table 8.

When applying a level of evidence approach, it was found that the Nana protocol had a strong level of evidence regarding DXA test-retest reliability, based on high quality articles as assessed by the CAT (Table 7), whilst the NHANES positioning protocol was deemed to have only a moderate level of evidence regarding reliability. This was due to only two high quality studies being reported in the literature for the NHANES positioning protocol, when available studies were assessed using the CAT (Table 7). Where no positioning protocol was reported in a study or a positioning protocol was not detailed, the level of evidence was deemed to be limited.

Table 8: Overview of results of studies of test-retest reliability of DXA measurements of BC

Authors	Variable/condition	Intrarater reliability between scans						High quality
		ICC or % change in mean* or % difference** or Pearson correlation #			CV% (TEM or SEM) or CL%* or limit of agreement #			
		BMC	LM	FM	BMC	LM	FM	
Bilsborough et al.[31]	Lunar — fan beam	1.00	1.00	0.99	0.60	0.30	2.50	Yes
Bilsborough et al.[31]	Lunar — pencil beam	1.00	1.00	0.98	1.50	0.50	5.90	Yes
Colyer et al.[32]	–	–	1.00	0.99	–	1.2*	1.2*	Yes
Covey et al.[28]	Discovery Wi machine ##	0.34**	−0.07**	0.29**	−0.04 to 0.06#	−1.10 to 1.10#	−0.70 to 0.77#	No
Covey et al.[28]	QDR machine ##	−0.40**	0.14**	−0.01**	−0.09 to 0.07#	−1.39 to 1.51#	−0.87 to 0.95#	No
Covey et al.[29]	QDR machine ##	−0.50**	0.30**	0.00**	−0.05 to 0.05#	−1.16 to 1.27#	−0.67 to 0.65#	No
Covey et al.[29]	Discovery Wi machine ##	0.20**	−0.10**	0.60**	−0.03 to 0.03#	−0.81 to 0.83#	−0.81 to 0.83#	No
Hurst et al.[33]	–	–	–	0.01*	–	–	–	No
Kerr et al.[11]	NHANES protocol	0.10*	−0.10*	0.20*	0.90	0.80	2.60	Yes
Kerr et al.[11]	NANA protocol	−0.40*	0.20*	−0.20*	1.00	0.60	2.20	Yes
Lohman et al.[30]	–	0.99#	0.99#	1.00#	–	–	–	No#
Moon et al.[34]	–	–	0.87F 0.95M#	–	–	–	–	No#
Nana et al.[1]	Immediate retest	−0.10F 0.30M*	0.20F 0.00M*	0.00F −0.40M*	1.00F 0.70M	0.50F 0.40M	1.30F 1.90M	Yes
Nana et al.[1]	Retest 24 h later	−0.30F −0.20M*	0.00F −0.20M*	−0.40F −0.60M*	1.10F 0.70M	1.00F 0.50M	1.30F 2.10M	Yes
Nana et al.[8]	Strength group	0.00*	0.00*	0.10*	1.00	0.60	2.50	Yes
Nana et al.[8]	Cycling group	−0.10F 1.90M*	0.30F 0.00M*	−0.10F −0.10M*	0.80F 5.20M	0.80F 1.50M	1.90F 1.40M	Yes
Smith-Ryan et al.[26]	–	–	0.996	0.995	–	0.83	0.99	Yes
Wilson et al.[27]	–	0.85 ̂total mass			1.08 total mass			No

BMC: bone mineral content, LM: lean mass, FM: fat mass, ICC: intraclass correlation coefficient, CV%: percentage of coefficient of variation, CL%: confidence limit percentage, ̂: root square mean error, ##: regional assessment of trunk only, CV% TEM (typical error of measurement) or SEM (standard error of measurement) percentage, F: female, M: male.

Discussion

This literature review included twelve studies of test-retest reliability of DXA measurements when used to assess BC in healthy cohorts. The findings of these studies can assist in determining what factors need to be accounted for when using DXA scans to assess individuals for BC, to achieve high test-retest reliability in DXA results. Studies that accounted for both sources of technical error (scanner qualifications, reduction of chance of artefacts affecting results, the positioning protocol followed) and sources of biological error (hydration, stomach content and food consumption, time of day of scanning and effects of physical activity) were found to have superior methodologies and reported greater DXA test-retest reliability.

Additionally, this review examined which DXA positioning protocol for assessment of BC (Nana, NHANES, no specified protocol or no protocol) had the highest level of evidence regarding test-retest reliability. It was evident that the Nana positioning protocol had the highest level of evidence regarding test-retest reliability of associated DXA results and this protocol was also deemed the most reliable protocol when conducting DXA scans for this purpose.

The Nana positioning protocol requires a participant to use of pads, which are transparent under DXA to minimize movement as well as increase reproducibility. Assessment of the studies of Nana et al.,[217] Nana et al.[226] and Kerr et al.[229] indicated the Nana positioning protocol was the most reliable based upon three considerations. Firstly, the critical appraisal of the methodological quality of these studies indicated they were high quality studies; secondly, the reliability results reported in these studies indicated high test-retest reliability of the DXA results: and lastly, the methodological provisions employed in these studies to minimize biological and technical errors were robust. The results of this review, therefore, support the findings of Kerr et al.[229] that the Nana positioning protocol produces quality and reliable results; and also reinforces the original work of Nana et al.[217] in the development of a superior positioning protocol.

The reliability of the NHANES positioning protocol in assessing BC has only been assessed in two studies[229,249] and therefore can only be judged from a moderate level of evidence. The NHANES positioning protocol requires the participant to assume a supine position, with palms flat on the table and a strap securing the lower limbs to minimize movement.[228] According to our CAT assessment, the overall methodological quality of these articles was high. The statistical results and methodological provisions to minimize technical and biological errors also appear to be sound. However, it is important to note that one of the included studies[249] lacks provision for the participant to be rested and standardization of time of scanning. Ultimately, more high quality research is required for the NHANES positioning protocol before it could be recommended, based upon the criteria used in this review.

The level of evidence is limited from studies[244,246-248,250] which have not followed a specific positioning protocol such as the Nana or NHANES protocol. This is a result of low methodological quality of these studies. The results not surprisingly indicate lower reliability of DXA results when using such poorly-defined protocols. Additionally, all of the studies of this type did not include methodological provisions to standardize the participants to limit biological and technical errors.

A limited level of evidence was also yielded by studies [245,251,252] that did not include a description of the positioning of the participants in the methods. This omission resulted in poor CAT scores and was associated with fluctuations in reported DXA results and the omission of methodological provisions to overcome sources of biological and technical errors.

Therefore, when scanning individuals using DXA to assess BC it is advised that clinicians use a positioning protocol such as the Nana[217] or NHANES[228] protocols to minimize technical errors and that they ensure the technician performing the scans is qualified. Additionally, accounting for biological sources of error (hydration, stomach content and food consumption, time of day of scanning and effects of physical activity) is vitally important when using the afore mentioned positioning protocols. Of these two protocols, the Nana protocol currently has the highest level of evidence indicating that it should be the preference for clinicians.

Interestingly, Kerr et al.[229] also included a measure of comfort of participants. In this study, they used a modified version of the Nana positioning protocol (adding straps around the waist to secure the arms and the distal lower limb to “minimise any subject movement”) and a modified version of the NHANES positioning protocol (in which the participants hands were placed against the body but not secured). It could be postulated that these changes to the original positioning protocols may have favored the Nana positioning protocol, as subjects in the NHANES protocol had to actively hold their arms in a static position during the DXA scan. Perhaps not surprisingly, then, the Nana protocol was favored by participants based on comfort.

Limitations of this literature review include the non-inclusion of grey literature, and the focus of the literature review being only test-retest reliability. This latter focus may have excluded some studies which did not report test-retest reliability in their abstracts. The removal of non-English studies and the exclusion criterion of non-healthy subjects may have also reduced the number of included studies in this review. Additionally, this review only focused on whole body BC scans and did not include hemiscans or compilation of partial scans, as there is a shortage of articles investigating this technique.

Strengths of this literature review include the systematic approach employed and the rigorous methodology followed, using the PRISMA statement[231] as a guide. Additionally, the utilization of the modified CAT tool and independent reviewers aided and upheld high quality assessments of methodological quality. Furthermore, this is the only literature review to assess multiple variables in the methodology that affect the reliability of DXA measurements of SBC.

This literature review has affirmed the need for more high quality research to assess the test-retest reliability of DXA measurements of BC using the NHANES positioning protocol. Clinicians would benefit from research that more robustly compares the Nana and the NHANES positioning protocols. Robust further research would serve to elevate the NHANES positioning protocol to a similar level of evidence as the Nana positioning protocol. It is possible that if both protocols are shown to be associated with high levels of test-retest reliability based on high levels of evidence, the decision of the clinician regarding which to use then be based purely on the comfort of the individual being scanned, which should also therefore be assessed in future research.

Conclusion

This review aimed to assess the different protocols and methodological approaches used to reduce technical and biological errors in previously published studies that have investigated test-retest reliability of DXA when used to assess BC. The results of this literature review can usefully guide for future clinicians using DXA to assess BC in a variety of settings including elite sport, community health and research. As such, this review indicates that the Nana positioning protocol, when coupled with methodological provisions to minimize biological and technical sources of error, is the positioning protocol with the strongest level of evidence and high levels of test-retest reliability, and thus should be the choice of clinicians when using DXA to assess BC. Currently, moderate level evidence of high test-retest reliability exists for the NHANES positioning protocol and more high quality research using this protocol is required to enhance the level of available evidence. Not using a positioning protocol or not reporting the protocol employed means studies of DXA reliability are then of low methodological quality; too low to enable recommendations to be made based on their findings.

Practical implications

Methodological provisions to reduce technical errors and biological errors is of paramount importance to produce reliable DXA measurements of BC.

The use of positioning protocols in such DXA scanning increases the reliability of results.

To minimize technical error, the Nana positioning protocol should be the first choice for clinicians when assessing BC.

4.2 Investigating the level of agreement of two positioning protocols when using Dual Energy X-Ray Absorptiometry (DXA) in the assessment of Body Composition (BC).

Abstract

Background: Dual energy X-ray absorptiometry (DXA) is a commonly used instrument for analyzing segmental body composition (BC). The information from the scan guides treatment of conditions such as obesity and can be used to monitor recovery following injury. Two commonly used DXA positioning protocols have been identified - the Nana positioning protocol and the National Health and Nutrition Examination Survey (NHANES). Both have been shown to be reliable. However, only one study has assessed the level of agreement between the results of the protocols and participants' preference of protocol based on comfort. Given the paucity of research in the field and the growing use of DXA in both healthy and pathological populations further research determining the most appropriate protocol is warranted. Therefore, the aims of this study were to assess the level of agreement between results from the NHANES protocol and Nana protocol, and the participants' preference of protocol based on comfort.

Methods: Thirty healthy participants (15 males, 15 females, aged 23 to 59 years) volunteered to participate in this study. These participants underwent two whole body DXA scans in a single morning (Nana positioning protocol and NHANES positioning protocol), in a randomized order. Each participant attended for scanning wearing minimal clothing and having fasted overnight, refrained from exercise in the past 24hrs and voided their bladders. Level of agreement, comparing NAHNES to Nana protocol was assessed using an intraclass correlation coefficient (ICC), concordance correlation coefficient (CCC) and percentage change in mean. Limit of agreement comparing the two protocols were assessed using plots, mean difference and confidence limits. Participants were asked to indicate the protocol they found most comfortable.

Results: When assessing level of agreement between protocols both the ICC and CCC scores were very high and ranged from 0.987 to 0.997 for whole body composition, indicating excellent agreement between the Nana and NHANES protocols. Regional analysis (arms, legs, trunk) ICC scores, ranged between 0.966 to 0.996, CCC ranged between 0.964 and 0.997, change in mean percentage ranged between -0.58% and 0.37% which indicated a very high level of agreement. Limit of agreement analysis using mean difference ranged between -0.223 and 0.686kg and 95% CL produced results ranging between -1.262kg and 1.630kg. The majority (80%) of participants found the NHANES positioning protocol more comfortable.

Discussion: This study reveals a strong level of agreement as illustrated by high ICC's and CCC's between the positioning protocols, however systematic bias within limit of agreement plot and a large difference in 95% confidence limits indicates that the protocols should not be interchanged when assessing an individual. The NHANES protocol affords greater participant comfort.

Keywords: DXA, DEXA, Level of agreement, Body Composition

Introduction

Tissue composition assessment and analysis is commonly undertaken by using Dual-Energy X-Ray Absorptiometry (DXA).[217] The need for a device to accurately and effectively measure bone mineral density as an indicator of an individual's bone health, drove the development and implementation of the DXA scanner.[220] Dual Energy X-Ray Absorptiometry emits energy sources that are absorbed at different rates relative to the type of tissue they encounter; thus enabling clear imagining of different tissues (fat mass, lean mass and bone) based on the distinctive elements of these tissues.[222] Due to these distinct properties of measurement, the DXA scan calculates an individual's total BC, together with an individual´s regional BC; thus, the DXA is a popular instrument in research and clinical settings. Furthermore, DXA produces 0.004 mSv of radiation in each BC scan, equating to less than 1% of the maximum radiation dosage of 5 mSv in a year, as described by Australian Radiation Protection and Nuclear Safety Agency.[253] Therefore, the minimal level of radiation from DXA scans enables researchers and clinicians to widely use this instrument to assess BC on regular basis. Research drawn from BC scans have assisted clinicians and researchers to further their understanding of a number of conditions, including obesity and undernourished individuals.[223] When applying BC scanning to athletes, it has been identified that those with higher muscle mass in pre-season, have a decreased likelihood of suffering bone-related injuries during the season.[224] Nevertheless, it is important to note that the DXA's reliability must be ascertained prior to statistical data being extracted, analyzed and applied within a clinical and or sporting population.

In previous studies a variety of statistical analysis methods have been undertaken including intra-class correlation coefficients (ICC), percentage change and Pearson correlations to assess the reliability of the DXA, all of which have found DXA to be reliable.[217,226,229,244,246-250,252] However higher reliability is found in studies that account for biological and technical errors, especially the use of a reproducible positioning protocol. The National Centre for Health Statistics, National Health and Nutrition Examination Survey (NHANES) body composition positioning protocol[228] and the Nana positioning protocol, founded by Alisa Nana, are the two most popularly used protocols.[217] It is important to note the Australian and New Zealand Bone Mineral Society (ANZBMS) employs the same body position as the NHANES positioning protocol.

Shiel et al. (unpublished data) have systematically assessed studies using the Nana and NHANES positioning protocols and concluded that there is a high level of evidence and excellent reliability for the Nana positioning protocol, and a moderate level of evidence but excellent reliability for the NHANES, and therefore the Nana protocol should be considered the gold standard for BC DXA scanning. Kerr et al.,[229] is the only study to date which has compared the Nana and NHANES positioning protocols; concluding that the Nana protocol's reliability is superior in assessment of regional BC, fat mass (FM) and bone mineral content (BMC). This study also recommended that positioning protocols should not be interchanged, and proposes that the Nana positioning protocol is the more comfortable for the participant. [229] However, it should be noted that the Kerr study has used modified versions of the original protocols, which may have altered the participants perceived comfort level during the scan.

As such the primary aim of our study is to conduct an independent comparison of the Nana and NHANES positioning protocols in terms of results and level of agreement. The finding of this research will either strengthen the findings suggesting the Nana protocol produces superior results or increase the level of evidence for the NHANES protocol. Additionally, this study aimed to assess which of the two main positioning protocols identified in the published literature is more comfortable.

Methods

Study overview

During a single session, a participant was scanned twice, and repositioned between each scan. The two scans consisted of one Nana positioning protocol scans, with feet and hands positioned in radio-opaque pads; and one NHANES positioning protocol scan, with hands faced down on scanning bed. The order of the positioning protocol scans was randomized. The participant was asked to give their opinion on which positioning protocol, Nana or NHANES, was the most comfortable, and why they selected that positioning protocol.

Participants

Fifteen males, fifteen females (n=30) were recruited from Bond University and the greater public to partake in this reliability study. Thirty participants were selected based on the previously published recommendations for reliability studies [254]. Participants underwent an anthropometrical analysis of height using a Stadiometer (Harpenden, Holtain Limited, Crymych, UK) and mass using scales (WM202, Wedderburn, Bilinga, Australia) before partaking in BC scanning on the DXA machine. Participant characteristics can be found in Table 9. Prior to partaking in the study, all participants were informed of the testing procedures and signed a consent form. The study has been granted ethics approval by Bond University Human Research Ethics Committee (15221).

Table 9: Participants' characteristics

	Males (15)	Females (15)	Group (30)
Age (yr)	27.8 ± 7.2	31.3 ± 11.9	29.6 ± 10.1
Height (cm)	178.7 ±7.3	164.7 ± 8.9	171.7 ± 10.7
Mass (kg)	78.9 ± 8.8	62.4 ± 9.7	70.6 ± 12.4

Standardized Baseline Conditions

On the morning of the scan, the participant confirmed that they had fasted overnight; rested and refrained from exercise; wore minimal clothing (males: underwear, females: underwear, sports bra or two piece bathers); bladders were voided; as well as jewelry and metal removed, prior to scanning.

DXA instrument

BC was measured using a narrow angle fan beam Lunar Prodigy DXA machine (GE Healthcare, Madison, WI) with automatic analysis performed using GE enCore 2016 software (GE Healthcare). DXA provides three-component approximation of bone tissue and soft tissue (lean tissue, ie, muscle) and fat tissue.[85] The DXA was calibrated daily prior to any scans using a phantom as per manufacturer's guidelines. The machine used for the study has previously been found to produce very high reliability for BMD (0.998), lean mass (0.989) and fat mass (0.995).[51]

Standardized DXA operational protocol

All scans were performed by one qualified scanner and analyzed automatically by the GE enCORE 2016 software. Two BC protocols were utilized, the NHANES positioning protocol and the Nana positioning protocol (Figure 23). The NHANES protocol required the participant to be positioned in a supine position in the middle of the densitometry table with head straight, space between the arms and torso, palms flat on the table, and feet together secured by a strap.[228] When utilizing the Nana positioning protocol, participants were centrally aligned in the scanning area with their feet placed in a custom-made foam block to maintain a consistent distance between the subject's feet (15 cm) in each scan.

The custom-made foot blocks were made from Styrofoam and were transparent under the DXA scan. Additionally, the subject's hands were placed in custom-made foam and plastic paddles to ensure a mid-prone position with a standardized gap (3 cm) between the palms and trunk. These hand paddles created minimal changes to the scan analysis. Additionally, a strap around the ankles was utilized as per the NHANES protocol, to ensure that the only difference between protocols was the positioning block/paddles.

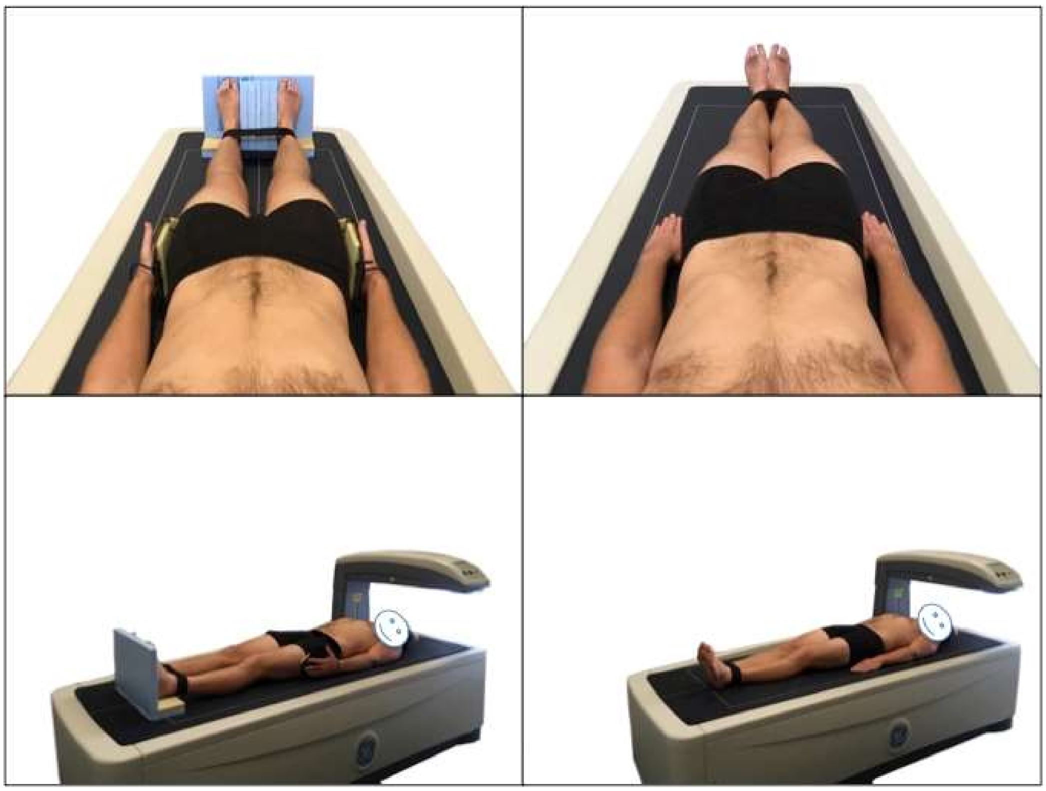


Figure 23: Nana positioning protocol (left images) and NHANES positioning protocol (right images)

- Statistical Analysis

IBM SPSS (version 24.0) and a custom spreadsheet from Sportscience web site (www.sportsci.org) were used to analyze and present the gathered data. Anthropometrical data was presented as means and standardized deviations. IBM SPSS 24 was utilized to assess Intraclass Correlation Coefficient (3, 1) with Confidence Intervals (CI) and create Bland Altman plots. This specific ICC was selected, based on the published work of Trevethan.[255] Percentage change in mean and typical error were calculated using the customized Sportscience spreadsheet.

Results

All the collated results when comparing the Nana positioning protocol with the NHANES positioning protocol (Figure 24) are presented in Table 10. When assessing the BC using two different positioning protocols; the results of the whole body (Tissue, FM, LM and BMC) scans and all regional (arms, legs and trunk) scans were excellent based on ICC's and percentage change in mean statistics. The results are also illustrated in the Limit of Agreement analysis plots for whole body (Figure 25) and Table 11 for all regions.

Percentage change in mean when comparing the two protocols has produced results that range between -0.68% and 0.37%. Trunk was the regional area with the smallest variance of the four sites (whole body, arms, legs and trunk) as described in Table 10, with results ranging from 0.02% to 0.37%. Whole body scans produced the largest variance, with results ranging from -0.68% to 0.21%.

The typical error expressed as CV% of the agreement between the positioning protocols and produced results ranging between 0.01% and 0.42%. The parameter of BMC was assessed to produce the smallest typical error across the four different sites (whole body, arms, legs and trunk). The tissue parameter was found to be the highest in three of four assessment sites (arms, legs and trunk).

A very high level of agreement between the two positioning protocols is evident through an ICC ranging between 0.966 – 0.999. Whole body tissue produced the highest ICC of 0.999, with a 95% CI of 0.775 – 1.000. The fat of the arms produced the lowest ICC of 0.966, with a 95% CI of 0.923 – 0.984.

Additional to the ICC, the CCC illustrates very good results with the results ranging between 0.964 and 0.997. The whole body lean mass produced the highest result of 0.997 with 95% CL of 0.995 – 0.998. Similar to the ICC result the fat mass of the arms produced the lowest correlation of 0.964 with 95% CL 0.936 – 0.980.

Limit of Agreement analysis plots (Figure 25) for the whole body reveal a bias between the two measures when assessing tissue as the zero value lies outside of the interval. This indicates that the Nana protocol consistently produced larger values than the NHANES protocol. Limit of agreement analysis using mean difference between the protocols ranged between -0.223 and 0.686kg across the parameters with arm measures the smallest difference. The 95% CL produced results ranging from -1.262kg for the lower limit up to 1.630kg for the upper limit. All mean differences fell with the define CL except for the leg fat assessment.

When questioned about which protocol was the more comfortable, 24 out of 30 participants (80.0%) chose the NHANES positioning protocol as the more comfortable of the two protocols assessed.

Table 10: Level of agreement between Nana vs NHANES positioning protocols

		% Δ in mean	Typical error as CV%	ICC	CI (95%)	CCC	CL (95%)
Whole body	Tissue	−0.47	0.10	0.987	0.970–0.994	0.987	0.976–0.993
	Fat	0.21	0.30	0.997	0.992–0.999	0.997	0.994–0.998
	Lean	−0.68	0.32	0.997	0.905 - 0.999	0.997	0.995–0.998
	BMC	0.06	0.03	0.990	0.586–0.998	0.989	0.983–0.994
Arms	Tissue	−0.32	0.19	0.982	0.745–0.995	0.982	0.968–0.989
	Fat	0.08	0.13	0.966	0.923–0.984	0.964	0.936–0.980
	Lean	−0.39	0.15	0.980	0.329–0.996	0.980	0.966–0.980
	BMC	0.01	0.01	0.979	0.876–0.993	0.994	0.989–0.997
Legs	Tissue	−0.58	0.38	0.984	0.822–0.995	0.983	0.971–0.990
	Fat	−0.10	0.19	0.992	0.983–0.996	0.992	0.986–0.996
	Lean	−0.49	0.30	0.987	0.837–0.996	0.987	0.977–0.992
	BMC	0.02	0.01	0.996	0.795–0.999	0.997	0.998–0.999
Trunk	Tissue	0.37	0.42	0.993	0.977–0.997	0.993	0.987–0.996
	Fat	0.22	0.29	0.991	0.975–0.996	0.991	0.983–0.995
	Lean	0.18	0.39	0.993	0.986–0.997	0.993	0.988–0.996
	BMC	0.02	0.02	0.973	0.841–0.991	0.972	0.951–0.984

Notes.
% Δ in Mean, percentage change in mean; CV, confidence variance; ICC, intra-class correlation coefficient; CI, confidence interval; CCC, concordance correlation coefficient; CL, confidence limit.

Figure 24: Nana positioning protocol (left) and NHANES positioning protocol (right)

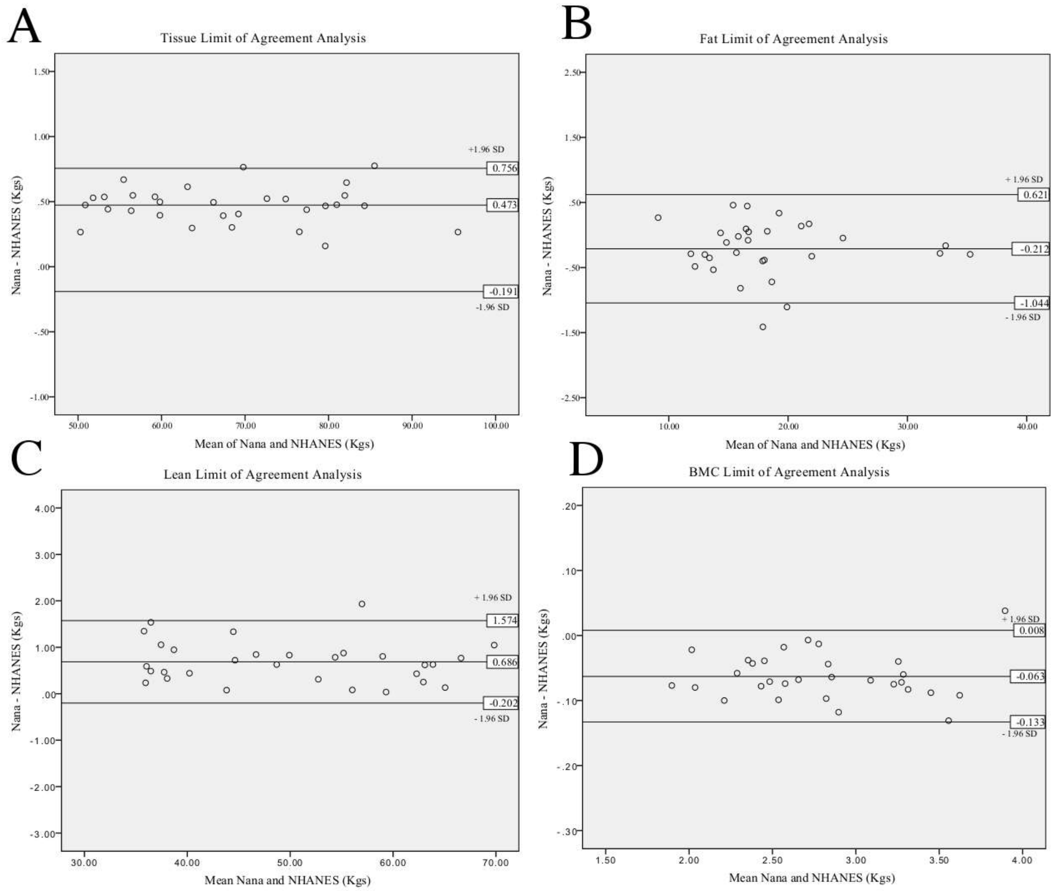


Figure 25: Limit of Agreement analysis for Nana versus NHANES whole body positioning protocols. Tissue analysis (A), fat analysis (B), lean analysis (C), BMC analysis (D)

Table 11: Limit of agreement between Nana vs NHANES positioning protocols

		Mean difference	Lower CL	Upper CL
Whole body	Tissue	0.473	−0.191	0.756
	Fat	−0.212	−0.621	1.044
	Lean	0.686	0.202	1.574
	BMC	−0.063	−0.133	0.008
Arms	Tissue	0.321	0.193	0.836
	Fat	−0.074	−0.432	0.283
	Lean	0.396	0.014	0.807
	BMC	0.000	−0.020	0.021
Legs	Tissue	0.586	0.458	1.630
	Fat	0.099	0.420	0.618
	Lean	0.488	0.350	1.327
	BMC	−0.005	−0.030	0.020
Trunk	Tissue	0.366	0.806	1.538
	Fat	−0.223	−1.017	0.572
	Lean	−0.176	−1.262	0.911
	BMC	−0.022	−0.071	0.027

Notes.
CL, Confidence Limit (95%).

Discussion

The primary aim of this study was to focus upon technical error associated with positioning and establish the level of agreement between the two identified positioning protocols. This study also sought to identify which DXA scan positioning protocol was the more comfortable for participants. In this study, we conducted all scans of BC using a Lunar DXA machine, located at Bond Institute of Health & Sport. To minimize the chance of technical error, one licensed researcher (qualified through ANZBMS) conducted all thirty scans as recommended for reliability studies.[254] To further decrease the chance of error swaying the results, biological factors such as time of day of scanning, hydration, exercise and food metabolism have been identified and accounted for.

This study found that the level of agreement between the Nana and the NHANES positioning protocols was very high when using a variety of statistics including percentage change in mean, accompanied with typical error, or ICC, accompanied with CI. The percentage change in mean findings of this study for the whole body (Tissue -0.47%, FM 0.21%, LM -0.68%, BMC 0.06%) is similar to the results of the previous study comparing the two protocols (Tissue -0.4%, FM -2.8%, LM 0.3%, BMC -0.7%).[229] The results of this studies regional analysis suggest that the level of agreement between the two protocols when doing regional analysis is also very good however these results are opposed to previously published research that conclude there is a large difference between protocol results.[229]

The assessed percentage change in mean in this study is smaller across the all parameters assessed except for whole body tissue mass in comparison to the only other study that has compared the two positioning protocols.[229] This may be due to the stringent methodology used in this study. As these studies have both accounted for biological error the source of difference can only be technical error. As such in this study, the NHANES protocol was followed as prescribed as in NHANES Body Composition Procedures Manual 2013.[228] The participant's feet were secured together with a strap and the hands were placed in a pronated position (palms down on the table), reducing the likelihood of movement artifacts. In comparison, the previous research conducted by Kerr and colleagues, the legs were secured with a strap but positioned a significant distance apart, possibly allowing for small amounts of internal rotation and adduction as these movements were not limited.[229] Furthermore, the hands were held in a neutral position, possibly allowing for small rotational movements. The combination of these two adjustments to the prescribed NHANES positioning protocol could possibly have created movement artifacts and altered results.

This is the first study to use an ICC to assess the level of agreement between the two positioning protocols. Very high ICC results are deemed to be between 0.90 and 1.00,[242] and our results (0.996 - 0.999) fall within this described range. Additionally, the concordance correlation results (0.964 – 0.997) coupled with the ICC results indicated that the level of agreement between the two positioning protocols is very high. However, this needs to be coupled with the mean difference and confidence limits analysis before deciding if the protocols are interchangeable.

The limits of agreement between the two positioning protocols when plotted into limit of agreement analysis plots (Figure 25) reveals a systematic bias in the parameter of whole body tissue. The systematic bias illustrates that the Nana protocol consistently produces higher results than the NHANES protocol, possibly due to the use of the foam blocks used to secure the feet. Additionally, Table 11 reveals that the mean difference lies outside of the defined 95% confidence limits for the leg fat parameter, this is due to this parameter having a large difference between the standard deviation and the mean when comparing the protocols. Applying the limit of agreement findings clinically illustrates a large variance, for example if the participant's lean mass was 50kg and mean difference 1.75kg then this equates to 4% change. These factors indicate that the two positioning protocols should not be used interchangeably even though the ICC results are very high.

When assessing which positioning protocol (Nana or NHANES) was deemed the most comfortable, this study found that 24 out of 30 participants (80.0%) chose the NHANES positioning protocol to be the most comfortable, this result is in direct opposition to previous findings.[229] Upon closer inspection of the methods employed, it appears Kerr and colleagues altered the original NHANES and Nana positioning protocols, which would have affected the perceived comfort levels of participants. The modified version of the NHANES positioning protocol they employed, would have required muscular activation and control; therefore, decreasing the participant's perceived comfort. When using the Nana positioning protocol, a strap was added to the original Nana protocol, which secured the participant's arms for approximately seven minutes during scanning; hence decreasing the muscular activation and increasing the participant's perceived comfort. In our study, the majority of participants who chose the NHANES as the most comfortable did so, because they felt their hands and arms were in a more relaxed position.

The Nana positioning protocol, where the feet are placed in radio-opaque blocks to maintain plantargrade ankle position; allows for taller individuals to be scanned with a decreased risk of plantar flexion and the participant's feet moving outside the scanning field [217]. Most individuals in our study over the height of

185cm, chose the Nana positioning protocol for comfort, and did so, based on not having to actively maintain their foot in plantargrade during the scan. Additionally, the Nana positioning protocols' use of pads to maintain the hands in a midprone position, allows for larger individuals (width wise) to be scanned more easily in comparison to the NHANES, where the individual's hands are pronated flat on the table.

Future research needs to investigate if certain positioning protocols are more applicable for different participants dependent upon their size. Furthermore, more research is required to ascertain the difference between the positioning protocols when using regional analysis.

The implications for clinical practice are that the decision of which positioning protocol to employ should be based on comfort, ie. the size of the participant's and not purely on the level of evidence for the protocols as both protocol produce very good results. As such, the NHANES protocol should be the first choice when scanning based on the comfort findings, however the Nana protocol provides a fantastic alternative for larger individuals.

Conclusion

When all sources of biological and technical errors have been accounted for, the Nana and NHANES positioning protocols both produce a very high level of agreement as demonstrated by very high results. However, the systematic bias revealed in the limit of agreement plot and the large 95% CL indicated that the two protocols should not be used interchangeably. Anecdotally, the NHANES positioning protocol was more comfortable.

4.3 Reliability and Precision of the Nana Protocol when assessing Body Composition using Dual Energy X-Ray Absorptiometry.

Abstract

Background: The Nana positioning protocol is widely used to position participants to minimize technical error when undertaking body composition scanning and analysis with a Dual Energy X-Ray Absorptiometry (DXA) machine. Once biological and technical errors are accounted for, the only variation in test re-test results is from statistical fluctuation or machine error. Therefore, the aim of this study is to assess the test re-test reliability of the Nana positioning protocol, and establish the smallest real difference percentage (SRD%).

Methods: A gender balanced group of thirty participants (15 males, 15 females) underwent two scans in succession using the Nana positioning protocol, with repositioning between scans. Percentage change in mean with typical error, Intraclass Correlation Coefficients (ICC) and smallest error measurement percentage (SEM%) were used to identify the test re-test reliability and error rate of these protocols. Additionally, SRD% was calculated to assess the point at which clinically important changes occurred in a participant.

Results: The reliability of the whole body and regional scans were excellent. Percentage change in mean ranged between 0.00% and 0.23%. High reproducibility of the Nana positioning protocol was evident through an ICC ranging between 0.966 – 1.000. Additionally, the error statistics of typical error, SEM% and SRD% were all low. Interestingly, fat mass was found to create the largest fluctuation of the parameters assessed.

Conclusion: When all sources of biological and technical errors have been accounted for the Nana positioning protocol has excellent test re-test reliability and produces low SEM% and SRD%.

Keywords: DXA; Test Re-test; Smallest Real Difference

Introduction

Dual-Energy X-Ray Absorptiometry (DXA) is a commonly used method to assess and analyze tissue composition.[217] The demand for extracting accurate and effective information regarding an individual´s bone mineral density, led to the design and development of the DXA machine.[220] Clear imaging of different tissue types (lean mass [LM], fat mass [FM] and bone) is enabled by the different absorption rates of the tissues when exposed to the different energy levels emitted by the DXA scanner.[222] These absorption rates can calculate the whole-body composition (BC) and the regional BC of an individual.[222] These distinctive properties have made the DXA machine a popular tool in clinical and research settings. Furthermore, the combination of the low radiation produced in a BC scan using DXA (less than a thousandth of the maximum recommended dosage of 5mSv) and the relative speed and affordability of scanning, allows for DXA's wide spread use to scan both adults and children in both clinical and research settings on regular occasions.[253,256]

Dual energy X-ray absorptiometry BC scans have enabled clinicians and researchers to gain a greater understanding into both the pathogenic processes involved a variety of conditions (obesity, diabetes, undernourished individuals, renal, gastrointestinal diseases) and the physiological changes in healthy populations associated with the process of growth and aging.[223,256] Body composition scans are also used extensively in athletic populations to investigate of physiological and para-physiological conditions affecting athlete performance.[256] As such, BC scans have been used to identify that players with higher preseason muscle mass are less likely to suffer a bone related injury during the following season.[224] Before the data obtained from BC scan can be used to alter treatment or training strategies it is vitally important to ascertain the DXA machines reliability and understand and account for sources of error.

Hologic or Lunar DXA machines have previously been tested for reliability. Results revealed LM ranging from 0.99 to 1.00 using an ICC; the Pearson correlations produced consistent results between 0.87 and 0.99; results ranged between -0.07% to 0.30% when using percentage difference; and finally, results ranged from 0.00% to 0.95% when using percentage change in mean.[217,226,229,244,246-250,252] The FM mimicked similar results with the ICCs ranging between 0.98 and 0.99; the Pearson correlation displaying 1.00; percentage difference ranging between 0.00% and 0.60%; and finally, the percentage change in mean produced 0.00% to 0.60%.[217,226,229,244,246-250]

To produce the highest possible reliable results, provisions in methodology are required to minimize the chance and occurrence of errors (biological and technical) creating false or misleading results.[225] The most important provision to minimize technical errors and ensure reliable results is the provision in methodology to use a consistent manner in which participants are positioned. As such two such positioning protocols exists, the National Centre for Health Statistics, National Health and Nutrition Examination Survey (NHANES) Body Composition positioning protocol and the Nana positioning protocol.[217,228] These two positioning protocols are used to minimize the movement of the participant during scanning which creates artifacts. The NHANES positioning protocol (or a modified version) displayed a 0.20% percentage change in mean and or an ICC which ranged between 0.98 and 1.00.[229,249] Whereas, the Nana positioning protocol showed similar results which produced a percentage change in mean in LM ranging between 0.00% to 0.30%; and FM ranging between 0.00% to 0.60%.[217,226,229]

Whilst conducting a systematic assessment of the two positioning protocols it was found there was a high level of evidence and excellent reliability for the Nana positioning protocol; whilst the NHANES protocol had a moderate level but excellent reliability. The Nana protocol's higher evidence base was the reasoning for its selection as the focus of this study.

Additionally, to biological and technical error affecting the results the concept of machine error and statistical fluctuation is paramount when attempting to determine the reliability and precision of an instrument such as a DXA machine. Standard error of measurement (SEM) (the square root within-subject variance) is a commonly used statistic that indicates the extent of measurement error that can be attributed to chance of variation in measurements.[254,258] The smallest real difference (SRD) or the smallest real difference percentage (SRD%) has been recognized as the benchmark statistic used to determine whether an individual has achieved real change beyond measurement error at the defined confidence level.[258,259] In this study, SRD% represents the maximum amount of change between DXA scans that can be attributed to statistical fluctuation or error. A arbitrary figure of an SRD% of less than 10% has been proposed and used previously to determine the acceptability of the value change associated with SRD.[260] Systematic search and review of the published literature pertaining to the DXA reliability scanning has revealed that no papers report a SRD or SRD%. Some papers report typical error, and this usually is expressed as a coefficient of variation percentage (CV%), which ranges between 0.3% and 5.9%.[217,226,229,244,249] Some previous authors have also calculated a smallest worthwhile effect (SWE) statistic; however there appears to be inconsistencies in the definition of this statistic. Most authors propose that the SWE is the smallest effect of an intervention that justifies the cost, risk and inconvenience of the intervention, and can only be calculated with subjective information from the participants who receive the intervention, and not by researchers or clinicians.[261-263] When the difference in results exceed the SWE, the intervention is deemed to be worthwhile, and when the difference between group means is less than the SWE, the intervention is deemed insufficiently effective. Other authors have calculated the SWE based on dividing the between-subject standard deviation by one third, as the standard deviation was three times greater than previous studies results in athletic populations.[217,226]

Technical error will be the core focus of this study; and therefore, the goal will be to assess the test re-test reliability of the Nana positioning protocol in total body and regional BC. Additionally, this study will also aim to calculate the SRD% between scans of the Nana protocol when assessing BC, instead of the SWE. This study is also the first study of the Nana positioning protocol to be truly independent and free from potential biases as it does not include the author of the Nana protocol, Ava Nana.

Methods

Study overview

Each session consisted of two scans; the Nana positioning protocol was conducted twice with feet and hands positioned in radio-opaque pads. Each subject was repositioned between scans, with the total session running for approximately fifteen minutes per subject.

Participants

Firstly, prior to commencing the research, this study was granted ethics approval by Bond University Human Research Ethics Committee (15221). Each subject was informed of all risks and testing procedure, with signed consent taking place prior to scans proceeding.

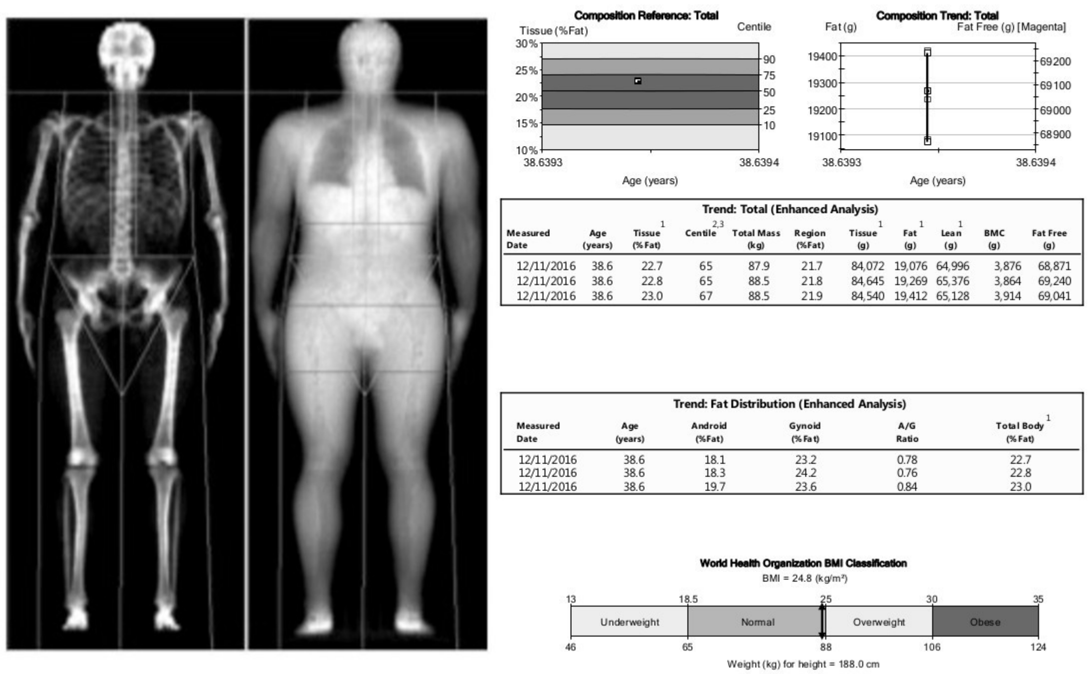
Secondly, a gender balanced group of fifteen males and females (n=30) were enlisted from Bond University Gold Coast, and the wider public of the Gold Coast community. The subject demographics were: females (n=15) age = 31.3 $\pm$ 11.9 years, height = 164.7 $\pm$ 8.9cm, mass = 62.4 $\pm$ 9.7 kg, and males (n=15), age = 27.8 $\pm$ 7.2 years, height = 178.7 $\pm$ 7.3 cm, mass = 78.9 $\pm$ 8.8 kg. The number of subjects were recruited based on recommendations published in previous reliability studies.[254] A Stadiometer (Harpenden, Holtain Limited, Crymych, UK) and scales (WM202, Wedderburn, Bilinga, Australia) were utilized to undertake an anthropometrical analysis of height and mass of each subject prior to BC scanning on the DXA machine.

Standardized Baseline Conditions

The subject reported for their morning scan having fasted overnight; refrained from exercise; and with their bladders voided. Male subjects wore minimal attire, ie, underwear, whereas female subjects wore either lingerie or bathers. Furthermore, all subjects were required to remove all metal.

DXA instrument and operation

The Lunar Prodigy DXA machine (GE Healthcare, Madison, WI) was calibrated every day according to the manufacture's guidelines, using a phantom. A qualified ANZBMS scanner performed each BC scan using the narrow angle fan beam DXA machine, and thereafter used the GE enCORE 2016 software (GE Healthcare) to analyze the data (Figure 26).



Trend: Total (Enhanced Analysis)

Measured Date	Age (years)	Tissue[1] (%Fat)	Centile[2,3]	Total Mass (kg)	Region (%Fat)	Tissue[1] (g)	Fat[1] (g)	Lean[1] (g)	BMC (g)	Fat Free (g)
12/11/2016	38.6	22.7	65	87.9	21.7	84,072	19,076	64,996	3,876	68,871
12/11/2016	38.6	22.8	65	88.5	21.8	84,645	19,269	65,376	3,864	69,240
12/11/2016	38.6	23.0	67	88.5	21.9	84,540	19,412	65,128	3,914	69,041

Trend: Fat Distribution (Enhanced Analysis)

Measured Date	Age (years)	Android (%Fat)	Gynoid (%Fat)	A/G Ratio	Total Body[1] (%Fat)
12/11/2016	38.6	18.1	23.2	0.78	22.7
12/11/2016	38.6	18.3	24.2	0.76	22.8
12/11/2016	38.6	19.7	23.6	0.84	23.0

Figure 26: Nana positioning protocol analysis

Nana body composition positioning protocol

During each scan, the Nana positioning protocol requires the subject´s feet to be placed on a transparent styrofoam block, which is custom-made to keep a consistent distance of 15cm between the feet; together with a strap around the ankles to keep movement minimal, and reduce artifacts. The subject also is placed centrally and in a supine position, with custom-made foam and plastic paddles used to position the subject´s hands in a mid-prone position with a consistent gap of 3 cm between the inside of the hands and the trunk; again, the hand paddles reduced the risk of any movements (Figure 27).

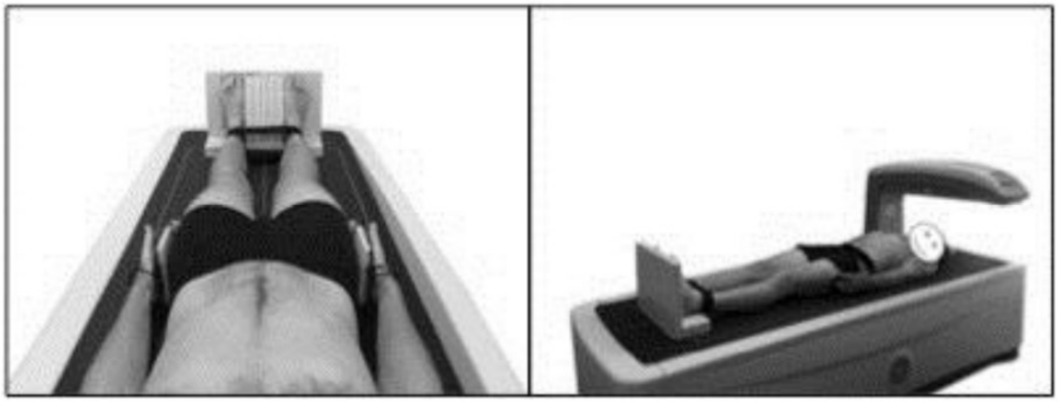


Figure 27: Nana positioning protocol

Statistical Analysis

This study used various statistical measurements to collect, analyze and present data. Firstly, IBM SPSS 24 and custom-made spreadsheets from the Sportsscience website (www.sportsci.org) aided with percentage change in mean, confidence intervals (CI), typical error as CV%, the standard error of measurement percentage (SEM%) (SEM=((√mean square error from ANOVA)/mean) x100), and smallest real difference percentage (SRD%) (SRD% = ((1.96 x SEM x √2)/mean) x100) calculations.[254] Based on Trevethan´s work on Intraclass Correlation Coefficient 3,1, this measurement is also utilized to extract data with the IBM SPSS 24.[255] Secondly, means and standardized deviations are displayed from anthropometrical data. Lastly, the data extracted from the SPSS is utilized to create Bland Altman plots.

Results

All the collated results from the Nana positioning protocol test re-test reliability are presented in Table 12. When assessing the BC on two different occasions with repositioning of the participant between each scan; the reliability of the whole body (Tissue, FM, LM and BMC) and all regional (arms, legs and trunk) scans were outstanding. These outstanding results are also shown in the Bland Altman plots (Figure 28), displaying close precision in all areas.

Table 12: Nana positioning protocol test-retest reliability

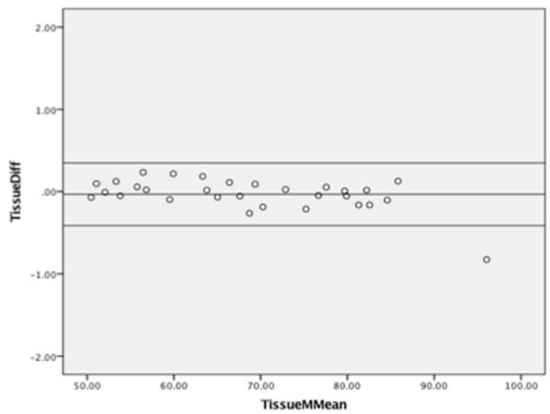
		% Λ in mean	Typical error as CV%	ICC	CI (95%)	SEM%	SRD%
whole body	Tissue	0.03	0.14	1.000	1.000 - 1.000	0.2	0.6
	Fat	0.23	0.36	0.996	0.990 – 0.998	2.1	5.9
	Lean	-0.03	0.75	0.996	0.991 - 0.998	1.5	4.1
	BMC	0.02	0.03	0.997	0.993 – 0.999	1.1	3.1
Regional arms	Tissue	0.00	0.10	0.998	0.996 – 0.999	1.1	3.0
	Fat	-0.02	0.08	0.986	0.972– 0.994	3.8	10.6
	Lean	0.02	0.11	0.997	0.995 – 0.999	1.7	4.7
	BMC	0.00	0.01	0.996	0.992 - 0.998	1.6*	4.5*
Regional legs	Tissue	0.07	0.29	0.996	0.991 – 0.998	1.2	3.3
	Fat	0.10	0.20	0.992	0.982 – 0.996	3.0	8.3
	Lean	-0.03	0.29	0.995	0.989 – 0.998	1.7	4.6
	BMC	0.00	0.01	0.996	0.998 – 0.999	0.8*	2.3*
Regional trunk	Tissue	-0.10	0.32	0.997	0.994 – 0.999	1.0	2.8
	Fat	0.12	0.33	0.990	0.979 – 0.995	4.0	11.1
	Lean	-0.23	0.45	0.991	0.981 – 0.996	2.0	5.5
	BMC	0.01	0.03	0.966	0.931 – 0.984	3.3*	9.1*

*assessed in milligrams

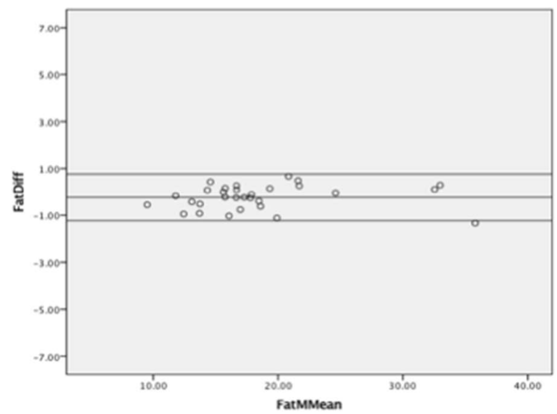
% Δ in Mean – percentage change in mean, CV- confidence variance, ICC – intraclass correlation coefficient, CI – confidence interval, SEM% - percentage standard error of measurement, SRD% - percentage smallest real difference

Percentage change in mean of the Nana positioning protocol has produced results that range between -0.23% and 0.23%. Arms were the regional area with the smallest variance of the parameters (whole body, arms, legs and trunk) as described in Table 12, with results ranging from -0.02% to 0.02%. Trunk was the largest variance area, with results ranging from -0.23% to 0.12%.

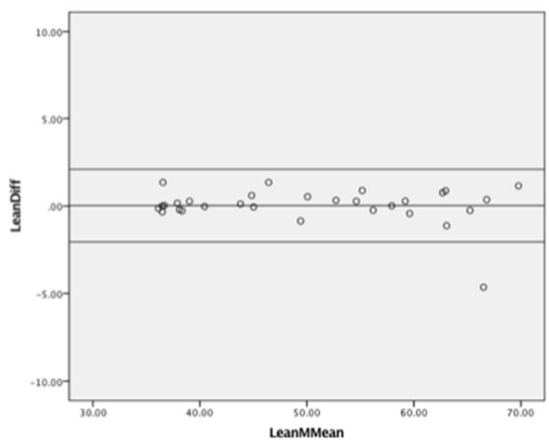
The typical error is expressed as CV% of the Nana positioning protocol has produced results ranging between 0.01% and 0.75%. The arms showed the smallest typical error in comparison to the other parameters in Table 12. The arms typical error ranging between 0.01% and 0.11%; whereas the other parameters showing 0.03% to 0.75%; with the whole body LM producing the largest value of 0.75%.



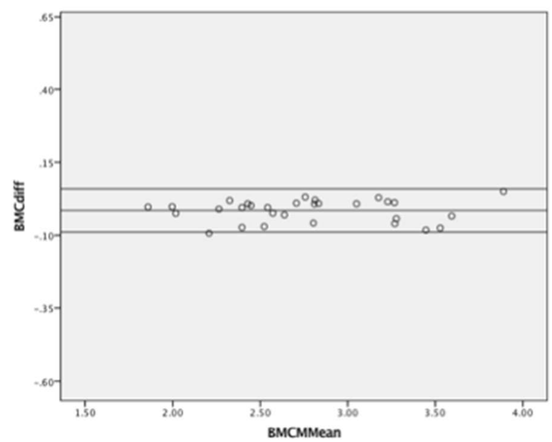
Nana vs Nana tissue mass



Nana vs Nana fat mass



Nana vs Nana lean mass



Nana vs Nana BMC

Figure 28: Bland Altman plots for whole body Nana versus Nana positioning

High reproducibility of the Nana positioning protocol is evident through an ICC ranging between 0.966 – 1.000. FM consistently presented the lowest ICC for whole body and regional scans except for trunk BMC which, produced the lowest ICC of 0.966, with a 95% CI of 0.931-0.984. Whole body tissue produced the highest ICC of 1.000, with a 95% CI of 1.000 – 1.000.

The SEM% reiterated the results of the ICC; with FM results consistently showing the highest SEM% of the four parameters. Tissue mass of whole body produced the lowest SEM% scores in comparison to the other parameters in Table 12.

Smallest real difference percentage (SRD%) also followed the pattern of ICC and SEM%; with FM displaying the highest results consistently in all four parameters; ranging between 5.9% and 11.1%. Tissue, LM and BMC illustrated an overall low SRD% score throughout, except for the regional trunk of BMC which indicated a high SRD% of 9%.

Discussion

To minimize the chance of technical error, a qualified ANZBMS scanner conducted thirty BC scans at Bond Institute of Health and Sport, using the Lunar DXA machine, with automatic analysis by the GE enCORE 2016 software. Thirty subjects were scanned based on the recommendations by Lexell and Downham regarding reliability studies.[254] Moreover, biological factors were also considered to minimize the chance of error possibly altering the results. For example, prior to scanning, the subject´s hydration level, exercise and food intake and time of scanning were all monitored.

The Nana positioning protocol produced excellent test re-test reliability results when the parameters of tissue mass, FM, LM and BMC were assessed in the total body, and regions of the arms, legs and trunk. These results confirm the findings of previous research indicating that the Nana positioning protocol is a reliable positioning protocol when assessed using a DXA machine.[217,226,229]

In this study, when percentage change in mean was used to analyze the data, the Nana positioning protocol produced similar results as previous studies which have used this statistic.[217,226,229] The actual figure of change in this study´s result was consistently lower in comparison to previous studies which utilized the Nana positioning protocol.[217,226,229] This may be possibly due to the strict methodology followed and that the machine used was relatively new. The results fluctuated among studies as to which parameter (tissue, FM, LM or BMC) produced the smallest change in mean from zero. Only the parameters of tissue mass when assessed on the whole body, together with BMC when assessed in the legs; produced results that were similar across all the studies. Consequently, these produced the smallest change in mean scores from zero in all studies.

When using percentage change in mean, it is required to present the typical error, this has usually been presented as a percentage of typical error otherwise known as a CV%.[240,264] The CV% results of this study, typically were smaller values when compared to other studies,[217,226,229] this is likely due to the previsions in methodology to reduce effects of biological and technical error. Once again differences occurred in regards to, which parameter produced the smallest percentage typical error. It was found that only BMC in the legs produced the same results across all studies.

This study is the only study so far to include ICC results for all parameters in whole body and regional. The ICC results of this study ranged between 0.966 and 1.000, demonstrating very high reliability.[242] Other studies, have presented ICC ranging between 0.4 to 0.99.[217,226] These results varied significantly as they have not reported ICC for individual variables but instead have reported overall figures.

To our knowledge, this is the first time that SRD% has been used when analyzing BC. In this study, the SRD% was calculated between 0.6% to 5.9% (whole body) and 2.3% and 11.1% (regional), thus providing an indication of the point at which real change occurs. Using SRD% produced results that were similar to the other studies that have used SWE, in that FM produced the largest figure that may be accounted to statistical error or fluctuation before a real change can be confidently assessed. As such SRD% should be calculated on each individual machine if longitudinal analysis of BC is being undertaken.

As the most fluctuation of SRD% scores occurred in the trunk and arm regions, authors postulate this may be due to automatic region of interest lines were applied automatically and adipose tissue may have encroached over the region of interest line into another region, ie, the arm fat may have been assessed in both the arm and trunk in one scan but may have been only in the arm region on the next scan. To address this possible issue, future research needs to be undertaken with ROI adjusted and standardized between patients.

In summary, once biological and technical errors have been justified, the Nana positioning protocols produced very high test re-test reliability, and therefore can be the trusted choice for clinicians assessing an individual’s BC.

Additionally, we urge future clinicians and researchers using the Nana positioning protocol to establish the SRD%. This calculation will enable a scanner to determine the figure at which a change in results can confidently be attributed to a true change of the participant between test re-test, and not due to statistical fluctuation or error.

4.4 Reliability of the Australian and New Zealand Bone Mineral Society positioning protocol for Bone Mineral Density using Dual Energy X-Ray Absorptiometry.

Abstract

Objectives: Investigate the previously not established reliability, measurement variability and clinically important changes in bone characteristics of the Australian and New Zealand Bone Mineral Society (ANZBMS) dual energy X-ray absorptiometry (DXA) positioning protocol when used to assess bone mineral density (BMD) of the lumbar spine, femoral neck and total hip. This research is vital as poor bone health such as osteoporosis causes a reduction in bone strength, which increases risks of fracture and reduces quality of life, costing the Australian Government in excess of $695 million annually.

Design: Prospective cohort study

Methods: In a single session, 30 healthy participants (15 males and 15 females, aged 23 to 59 years) underwent four BMD scans (two lumbar and two hip) in accordance with the ANZBMS DXA scanning protocol. Participants were repositioned between scans. Test-retest reliability was assessed by an intraclass correlation coefficient (ICC (3,1)) with 95% confidence intervals and by the percentage change in the mean. Standard error of measurement percentage (SEM%) and smallest real difference percentage (SRD%) were also calculated.

Results: Repeated DXA measurements of BMD of the lumbar spine, femoral neck and total hip produced results indicating excellent reliability. The total hip measurement was most reliable (% change in mean 0.09%, ICC 0.995, SEM% 0.77%, SRD% 2.13%), followed by the lumbar spine (% change in mean 0.02%, ICC 0.991, SEM% 0.92%, SRD% 2.53%) and femoral neck (% change in mean – 0.36%, ICC 0.984, SEM% 1.35%, SRD% 3.73%).

Conclusion: The ANZBMS positioning protocol for DXA assessment of BMD in the lumbar spine, femoral neck and total hip yields measurements with high intra-rater reliability. The SRD% scores recorded in this study will enable future

serial/longitudinal analysis of DXA BMD measurements to occur with greater understanding of how to interpret changes over time.

Keywords: DXA, Reliability, Test Retest Reliability, Bone Health, Osteoporosis

Introduction

A clinical diagnosis of osteopenia or osteoporosis is based on the measurement of an individual´s bone mineral density (BMD), which is quantified from the amount of mineral per square centimeter of bone.[10,233] Osteopenia - a decreased bone mass and a potential precursor to osteoporosis - is diagnosed when an individual's BMD falls between minus one and minus two and half standard deviation below the mean of a young adult.[9,10] Osteoporosis is a skeletal condition in which the bone density (mass/volume) of normal mineralized bone is significantly decreased; consequently reducing mechanical strength, and thus increasing risk of bone fractures.[267] This is diagnosed when an individual´s BMD falls below two and a half standard deviations of the mean of a young adult.[10] In 2006, it was estimated 1.2 million Australians were affected by osteoporosis and 6.3 million Australians were osteopenic. Additionally, it is estimated that osteoporosis is affecting 6% of men and 23% of women over the age of 50; and 12.9% of men and 42.5% of women aged 70 years and over.[9]

Fractures are a major concern for osteoporosis sufferers. In Australia, during 2012, 140,822 fractures occurred as a result of osteopenia and osteoporosis.[10] It is anticipated that by 2022 there will be a 30% rise in the number of fractures if action to improve the diagnosis and management of osteoporosis is not undertaken[10]. Furthermore, it is anticipated from 2013-2022 that the cost of associated fractures and poor bone health will reach $33.6 billion.[11] The common sites of fractures occurring for people with osteoporosis are hip, vertebrae, wrist and other areas not aforementioned. The hip is the most prevalent fracture site in females over age of 80 years and in males over 85 years.[11] The direct management (hospital, ambulance, community fracture management, rehabilitation, nursing home, community services, pharmaceuticals and supplements) of hip fractures costs the Australian government $695 million annually.[11]

A certain type of fracture known as a minimal trauma fracture is prevalent within osteopenia and osteoporosis sufferers; minimal trauma fractures are when a fracture occurs when a person falls no greater than their standing height.[10] In fact, over 78% of individuals with a history of minimal trauma fractures have either osteopenia or osteoporosis.[268] In 2006, 1,448 people over the age of 40, died as a result of a hip fracture; 24% of these were related to minimal trauma falls.[269] Consequently, minimal trauma fractures cause a significant burden to the health care system, due to the incapacity of an individual to live independently.[270]

Low BMD isn't only an issue in individuals with osteopenia or osteoporosis, it is also a significant issue in sporting populations. Assessments of female athletes have revealed that low BMD is predictive of stress fractures.[271,272] The incidence rate of lower limb stress fractures in track and field athletes, has been reported to be around 20% annually.[273] If stress fractures are not correctly treated and healed, it can cause a reduction in performance, an increase in pain, loss of training time and medical expenses; subsequently developing into a complete fracture, non-union, chronic pain, increased recovery time and possibly disability.[274,275]

As discussed, low BMD is the core of many conditions, and thus the need for accurate and effective BMD analysis of individuals led to the development of the Dual Energy X-Ray Absorptiometry (DXA) scanner.[220] DXA provides a clear illustration and analysis of an individual's bone health due to the absorption rates of the two different energy sources within DXA, and the unique elemental properties within bone, fat and lean tissue.[222] The amount of radiation produced by a DXA scan is very low, enabling its use to track an individual's bone health where scanning is required on regular basis. In this study, the total radiation exposure equated to 0.044 mSv, which falls well below the radiation levels to place an individual at risk, and equates to less than one chest x-ray with two views.[276]

Various companies manufacture DXA machines, and regardless of whether the machine is made by Hologic or Lunar companies, it has been found to be reliable when assessing BMD; with results ranging from 0.98 ICC for the proximal tibia and distal femur to 0.99 ICC for the hip and forearm.[277,278] When assessing the less common stress fracture site of the metatarsals, it was found the ICC ranged between 0.71 and 0.99.[279] Additionally, when Lohman and colleagues utilized a Pearson Correlation, they found that whole body BMD and upper limb and lower limb BMD ranged between 0.92 and 0.98.[248]

The main clinical sites for BMD assessment are the hip, the lumbar spine and forearm; based on the most highly common risk sites for fractures.[11] However, the reliability of a scan is very dependent on the ability to position a participant in a reproducible position.[85] Consequently, two positioning protocols have been identified; the Australian and New Zealand Bone Mineral Society (ANZBMS) and the National Health and Nutritional Examination Survey (NHANES) to ensure reliable results from each DXA scan.[85,228] Both protocols are similar; however some differences have been identified.

The ANZBMS positioning protocol for the lumbar spine requires a participant to lie supine on the table with hips and shoulders square, the feet and lower legs raised on a cushion block to create 60-90 angle at the hips to reduce lumbar lordosis and to separate the vertebral bodies.[85] The NHANES positioning protocol for lumbar spine BMD assessment involves the participant lying in a supine position on the table in a straight and square position.[228] The legs are placed on a cubed cushion with the hip flexed as close to 90 degrees as possible.[228] These two positioning protocols are very similar; however; the hip angle is the focus of the NHANES protocol, whereas the reduction of lumbar lordosis via hip angle is the focus of the ANZBMS protocol.

To date, there is a dearth of quality studies that have investigated the test re-test reliability of the ANZBMS positioning protocol in healthy adults when assessing the lumbar spine and hip BMD using the DXA. Therefore, the aim of this study is to ascertain the reliability, measurement variability and clinically important changes of the ANZBMS positioning protocol for the important clinical sites of the lumbar spine and hip.

Methods

Study overview

In a single session, participants underwent four BMD scans (two lumbar spine and two hip) in accordance with the ANZBMS scanning protocol; and were repositioned between scans. The scanning order was randomized to decrease possible bias. The ANZBMS positioning protocol was selected as the scanner who completed all scans was trained and accredited by the ANZBMS.

Participants

A total of thirty participants (fifteen males and fifteen females) were recruited from Bond University and the greater public to participate in this study; which has ethical approval from Bond University Human Research Ethics Committee (15221). Recruitment took place during October 2016 and December 2016. To be eligible for the study, participants were willing to meet scanning stipulations (fasted, bladder voided, removal of metal, abstained from exercise on day of scan and undertake anthropometric assessment). Participants were excluded from the study if they suspected they were pregnant and or were non-healthy - inclusive of osteoporosis, current fractures, hemiarthroplasty and total joint replacements, rheumatoid or osteoarthritis, current cardiac or pulmonary conditions, or diabetes.

To reduce the likelihood of artifacts, male participants wore underwear during scanning and female participants wore underwear and sports bra or two-piece bathers. Participants initially were informed of all testing procedures and completed a consent form. Participants were assessed for height using a Stadiometer (Harpenden, Holtain Limited, Crymych, UK) and mass using scales (WM202, Wedderburn, Bilinga, Australia) prior to scanning. Anthropometric data of the participants can be found in Table 13.

Table 13: Participants' characteristics

	Age (ys)	Height (cm)	Mass (kg)
Males (15)	27.8 $\pm$ 7.2	178.7 $\pm$ 7.3	78.9 $\pm$ 8.8
Females (15)	31.3$\pm$ 11.9	164.7 $\pm$ 8.9	62.4 $\pm$ 9.7
Total (30)	29.6 $\pm$ 10.1	171.7 $\pm$ 10.7	70.6 $\pm$ 12.4

DXA scans

All scans were performed by one qualified scanner using a narrow angle fan beam Lunar Prodigy DXA machine (GE Healthcare, Madison, WI). Scans were then analyzed automatically by the GE enCORE 2016 software (GE Healthcare) (Figure 29). The DXA machine was calibrated daily using a phantom as per manufacturer's guidelines. BMD scanning took place in accordance with the ANZBMS protocols.[85] For the lumbar scan, the participant lay supine in the middle of the densitometry table with feet and lower legs raised on a block in order to flatten the lumbar spine as shown in Figure 30. For the hip scan, the participant lay in a supine position in the middle of the densitometry table with the leg internally rotated 15 to 20 degrees so that the femoral head is parallel to scanning table. A foot block and velcro straps were used to secure the required position as shown in Figure 30.

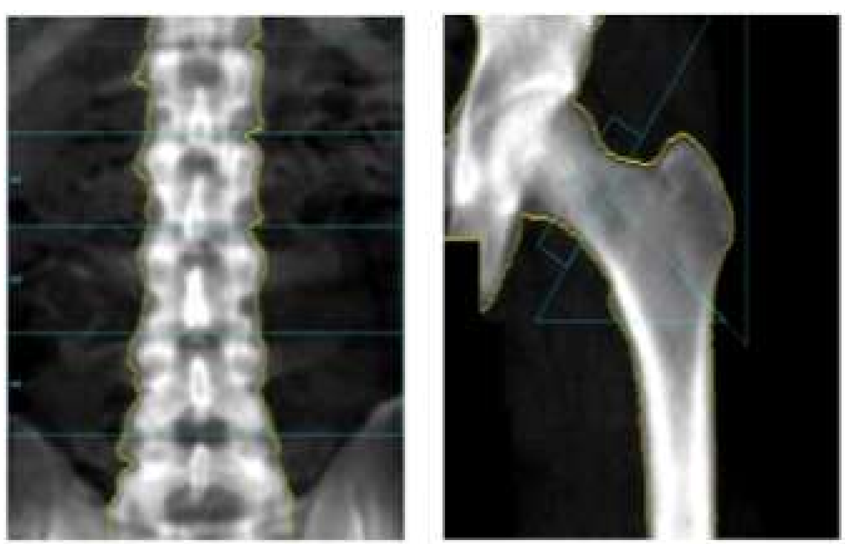


Figure 29: Lumbar spine analysis (left), hip analysis (right)

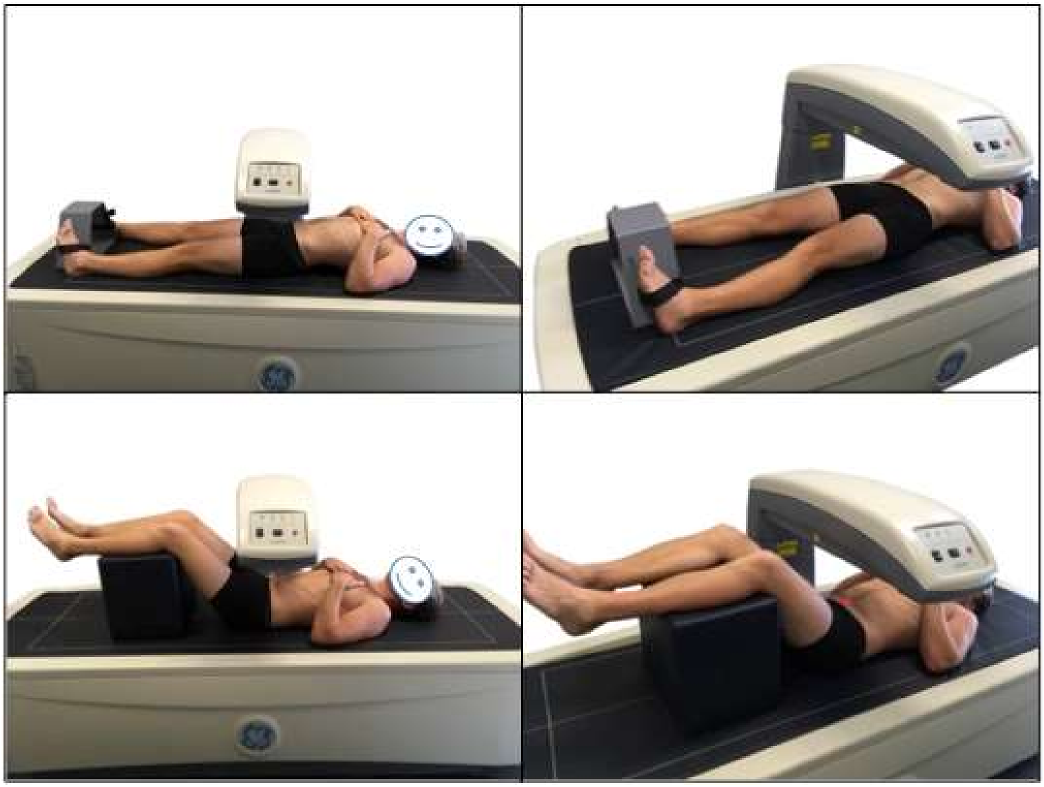


Figure 30: Proximal femur scan (top row) position, lumbar spine (bottom row) position

Statistical Analysis

All data was analyzed using either IBM statistical package for the social sciences (SPSS Inc., version 24, Chicago IL, 2017) or a customized spreadsheet from www.sportsci.org. SPSS was be used to analyze test re-test reliability. The recommended Intraclass Correlation Coefficient (3,1) with 95% confidence intervals was utilized.[238,255] Bland Altman plots were also created. Additionally, standard error of measurement percentage (SEM%) (Equation 1) and smallest real difference percentage (SRD%) (Equation 2) were calculated [254] as follows: SEM=((√mean square error from ANOVA)/mean)x100 (Equation 1); SRD%=((1.96 x SEM x √2)/mean)x100 (Equation 2). In order to calculate and analyze percentage change in mean results and the accompanying typical error (coefficient of variation (CV%) percentage) as recommended, a customized spreadsheet from Sportscience website (www.sportsci.org) was utilized[240,264].

Results

The BMD measurements of the lumbar spine, the proximal femur and the total hip produced results of very high reliability (Table 14). The similarities between the levels of precision represented by standard deviations for these sites is illustrated in the likeness of the Bland Altman plots, with none of the clinical sites assessed producing significantly different plots. When investigating and comparing the clinical sites, the total hip produced the most reliable results of the three clinical sites, when using the statistical analysis of an ICC; or a combination of percentage change in mean and typical error. However, when only a percentage change in mean was used, the lumbar spine demonstrated the most reliable of three clinical sites (Table 14). On the contrary, the femoral neck produced the least reliable results of the three clinical sites measured (Table 14). This was evident through the measurement of smallest real difference (SRD), which identified also that the femoral neck produced the greatest percentage difference between test and re-test.

Table 14: Results of scans

	% Δ in Mean	Typical Error as CV%	ICC	CI (95%)	SEM%	SRD%
Lumbar Spine	0.02	1.19	0.991	(0.982-0.996)	0.92	2.53
Femoral Neck	-0.36	1.51	0.984	(0.966-0.992)	1.35	3.73
Total Hip	0.09	0.87	0.995	(0.990-0.998)	0.77	2.13

% Δ in Mean – percentage change in mean, CV- confidence variance, ICC – intraclass correlation coefficient, CI – confidence interval, SEM% - percentage standard error of measurement, SRD% - percentage smallest real difference

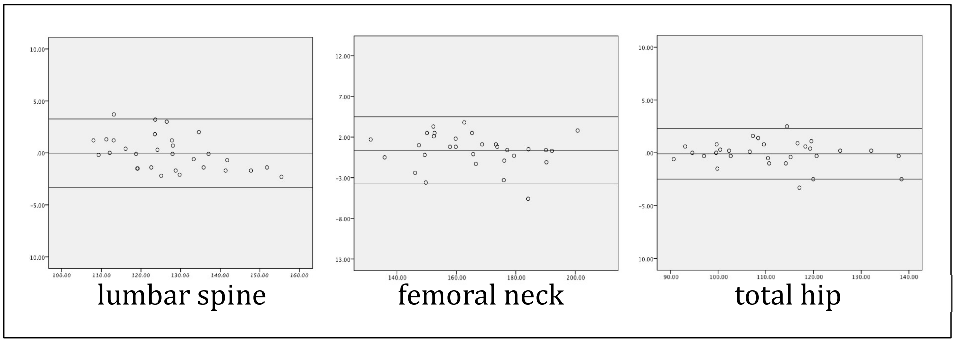


Figure 31: Bland Altman plots for lumbar spine, femoral neck and total hip

Discussion

The purpose of this study was to assess the test re-test reliability of the ANZBMS positioning protocol when using a DXA machine to measure BMD of the lumbar spine (L2-L4), the total hip and femoral neck. Our results indicated that when the Lunar DXA machine is used to assess BMD of the lumbar spine or the hip (total or femoral neck) it produces excellent reliability results (ICCs ranging from 0.984 to 0.991).[242] The percentage changes in mean results were also all under the respective typical error measurements, which is desirable when using this statistic.

Previous studies have assessed the reliability of BMD of the entire body, the hip, the forearm and the metatarsals in healthy cohorts.[248,277,279] To our knowledge, there is no study to date that has assessed the reproducibility of scanning of lumbar spine BMD in healthy subjects. Therefore, this is the first study to evaluate the test re-test reliability of BMD of the lumbar spine in a healthy population. The lumbar spine scans showed a percentage change in mean of 0.02% with a typical error of 1.19%, an ICC of 0.991, SEM% of 0.92 and SRD% of 2.53; all indicating very high reliability results with low error measurements. Therefore, these findings illustrate that the DXA machine used is reliable when assessing this clinical site, which is of utmost importance, as the lumbar spine is a common fracture site, representing 25 502 fractures in Australians over the age of 50, in 2012.[11]

The total hip scan BMD had a percentage change in mean of 0.01 with a typical error of 0.07, and an ICC of 0.995. The SEM% and SRD% were 0.77%

and 2.13% respectively. These results (ICC 0.995) were exactly the same as those from previous large-scale study's findings involving 195 participants.[277] Both studies have used a Lunar DXA machine; therefore, there is mounting evidence that the Lunar DXA machine produces excellent reliability results when assessing the total hip. The stringent methodology employed in this study, and the fact that this study has results that are identical to the Forsen research team, indicates validity of Forsen´s results, even though their study included a poorly reported methodology.

Surprisingly, no studies have included a specific scan of the femoral neck when assessing the BMD of the hip in healthy populations. A focus on the femoral neck when completing a total hip scan is crucial, as it has been shown that the neck of the femur is the most common fracture site of the hip complex.[269] Additionally, it is reported that the mortality rate post femoral neck fracture, at one year, is between 22 and 26%.[280,281] This study has found that the DXA machine, when using the ANZBMS hip positioning protocol, produces excellent reliability (ICC 0.984, percentage change in mean -0.36 with typical error 1.51%, a SEM% 1.35 and SRD% 3.73); therefore these consistent and reliable results further demonstrate that the DXA machine can be used clinically as a diagnostic tool when measuring BMD.

When comparing the three variables assessed in this study, the total hip scan produced the most reliable results, with results as high as ICC 0.995. This was slightly higher than the lumbar spine findings (ICC 0.991) and also higher than the femoral neck findings (ICC 0.984). The total hip also produced the best results when percentage change in mean was assessed with the typical error to give a true indication of the fluctuation of the results. Without this key value, the results would have been different. If using only a percentage change in mean, the lumbar spine would have been deemed as the most reliable of the three clinical sites tested. However, when typical error was included with the percentage change in mean, the total hip results were of the most reliable, echoing the results of the ICC statistic. This further adds credence to previous studies which have advised that percentage change in mean must be presented together with the typical error value when assessing test re-test reliability, to ensure consistent and accurate results.[240,264]

To the authors' knowledge, this paper is the first that looks at SRD% between the three clinical sites (total hip, femoral neck and lumbar) when analyzing BMD with a DXA machine. The precision of the Lunar DXA machine was evident in all sites with a SRD% score ranging between 2.13% - 3.73%. These findings could be invaluable in the future when assessing BMD changes over time, as this quantifies the amount of statistical fluctuation or errors in the results, and furthermore provides a figure at which real change in an individual begins.

This study is also the first study to assess the clinical sites of the lumbar spine and the femoral neck for test re-test reliability. Moreover, it is the first to calculate the SRD% that allows for a true indication of the change in an individual. Furthermore, the methodology approach undertaken throughout this study has been thorough by following ANZBMS positioning protocol and accounting for all biological and technical errors that could impact on the overall results. One limitation of this study was that it was conducted on healthy participants, all of whom could be positioned easily for lumbar and hip scans. Therefore, the immediate test re-test reliability of the DXA machine is uncertain when an individual is non-healthy (osteoporotic etc). Furthermore, as only one qualified operator was used, the inter-rater reliability was not established, which could make the results more applicable across the greater population.

Conclusions and Clinical Implications

Using ANZBMS positioning protocol to scan the BMD of clinical sites the lumbar spine, femoral neck and the total hip produces very high reliability. The error rate (typical error, SEM%, SRD%) associated with DXA scanning when using the ANZBMS positioning protocol is low. However, it is vitally important that researchers and clinicians should undertake their own reliability study as part of overarching studies, to ensure the machine they are using is reliable. Additionally, the machine's SRD% figure should be calculated to identify the smallest percentage change is attributed to statistical error. This will allow astute clinicians to be able to easily gauge if observed change is purely due to change in the individual.

Chapter 5: Bone health of middle-aged and older surfers

Preface

This chapter is the last in the first major section of this thesis, and it addresses two of the main objectives of this program of research: to analyze the relationships between surfing and bone mineral density (BMD) of middle-aged and older adults; and to analyse the relationships between surfing and bone metabolism via bone biomarkers.

As detailed in Chapter 2, to date there is only one study that has investigated the bone health of surfers. However, this study had limitations related to sample size and methods utilized.

Therefore, a cross-sectional, observational study design was conducted to examine the bone health of middle-aged and older surfers, by assessing traditional clinical sites via DXA scan, utilizing the positioning protocols detailed in Chapter 3. Additionally, biomarkers of bone turnover were also analyzed.

The present chapter was published in the Open Access Journal of Sports Medicine, and is formatted according to the journal's guidelines. A copy of the published manuscript is included in Appendix VII.

***Simas V**, Hing W, Rathbone E, Pope R, Beck B, Climstein M. Bone health of middle-aged and older surfers. Open Access J Sports Med. 2019 Sep 6;10:123-132. doi: 10.2147/OAJSM.S209043. eCollection 2019.*

Abstract

Purpose

Given the lack of research investigating surfing and bone health, we aimed to assess the bone mineral density (BMD) of middle-aged and older surfers.

Patients and methods

In a cross-sectional observational design, we compared a group of middle-aged and older surfers to a group of non-surfers, age- and sex-matched controls. Participants were males, aged between 50 to 75 years. Volunteers were assessed for body mass index (BMI), Bone-specific Physical Activity Questionnaire (BPAQ) scores, daily calcium intake, and alcohol intake. Primary outcomes included BMD at the femur and lumbar spine (LS), and T-score, assessed via dual-energy X-ray absorptiometry (DXA). Bone biomarkers were also analyzed.

Results

A total of 104 participants (59 surfers and 45 controls) were assessed. Groups were similar with regards to all demographic characteristics except for percentage of lean mass (higher in surfers, mean difference [MD] +2.57%; 95% confidence interval [CI] 0.05 to 5.09; p=0.046) and current BPAQ (cBPAQ) score (lower in surfers; MD -0.967; 95% CI -0.395 to -1.539; p=0.001). Surfers had a mean surfing experience of 41.2 (standard deviation [SD] ±11.8) years and mean surfing exposure of 26.9 (SD ±15.0) hours/month. Controls were divided into two groups, according to their main physical activity: weight-bearing/high intensity (WBHI) and non-weight-bearing/low intensity (NWBLI). When compared to NWBLI controls, surfers had higher LS BMD (MD +0.064; 95% CI 0.002 to 0.126; p=0.041) and higher T-score (MD +0.40; 95% CI 0.01 to 0.80; p=0.042); however, surfers had a lower T-score than the WBHI group (MD -0.52; 95% CI -0.02 to -1.0; p=0.039). No other differences were found between groups.

Conclusion

The findings of this study support our hypothesis that regular surfing may be an effective physical activity for middle-aged and older men to decrease bone

deterioration related to aging, as we identified positive results for surfers in relation to primary outcomes.

Keywords: Surfing, bone mineral density, osteoporosis, DXA, preventive medicine, sports medicine

Introduction

A physically active lifestyle is recognized as a preventative strategy for age-related bone deterioration that can lead to osteopenia and osteoporosis. A vast variety of exercise modes has been evaluated; however, not all types of exercise promote positive effects on bones.[18,109] For instance, walking and predominantly weight-supported activities, such as swimming and cycling, are associated with little, no, or even a negative effect on bone health.[22,128,130]

Surfing is a popular recreational activity and competitive sport. It is also one of the fastest growing sports in the world with participants estimated at 37 million worldwide in 2012,[44] a statistic which has more than doubled if compared to the 18 million surfers estimated in 2002).[45] Surfing is recognized as a quasi-weight bearing (ie, having a partial load-bearing component) aquatic-based physical activity.[49,50] Time-motion analysis of recreational surfers has indicated that surfers typically spend only three minutes standing up (ie, weight bearing) on the board (ie, actually surfing) in a 60-minute surf session.[49] Such a short period of weight bearing may not apply sufficient stimulus for positive bone remodeling. It could, therefore, be expected that participants in this aquatic activity may have an imbalance between osteoclastic (bone resorption) and osteoblastic (bone production) activity, resulting in degradation of bone mineral density (BMD) and consequently exposing surfers to premature development of osteoporosis and increased risk of fractures.

Nonetheless, surfing requires a wide range of physical qualities in order to paddle-out, pass through waves, “catch” a wave, balance on the surfboard, and execute and complete surfing maneuvers. It is possible that these additional actions, requiring considerable muscle exertions, enhance the stimulus to bone applied during a surfing session. Only one study has previously investigated bone health in surfers,[51] and findings suggested that surfing may be advantageous for bone. However, this study had a small sample size and did not utilize standard clinical site testing (ie, femur and lumbar spine) for bone health.

Therefore, the bone health of surfers is unclear, as there is no consensus on the effect of long-term surfing on BMD. Additionally, should preventive measures and recommendations to reduce the risk of bone deterioration be in place for this cohort? Consequently, bone health of middle-aged and older surfers should be a concern for clinicians. The aim of the current study, therefore, was to compare femur and lumbar spine BMD of middle-aged and older long-term male surfers with non-surfers in a larger sample than previously examined. The results will begin to inform clinical decisions regarding exercise recommendations for the prevention of osteopenia and osteoporosis in older men.

Methods

Study design

This research used a cross-sectional observational design to compare middle-aged and older male surfers to non-surfing, age- and sex-matched controls. The study was approved by the Bond University Human Research Ethics Committee (BUHREC 15221).

Participants

Surfers were recruited through advertising in a local newspaper and from local boardrider clubs in the Gold Coast (GC) area (city of Gold Coast, Queensland, Australia). Additional support was obtained from surfing magazines, websites and local surf shops in the GC area. Controls were recruited through advertisements at local community libraries, cafes, and clubs.

Eligibility criteria

Participants considered to be included in the study were males, aged between 50 to 75 years. Surfers were defined as those individuals who had been surfing for the past 15 years and were currently surfing regularly (at least twice a week). Surfers were excluded if they were currently participating in extensive resistance exercise, weight training or high impact activities, or if they were employed in or have been previously employed in a manual type of employment that would have a benefit for bone health. Participants in the control group were included if they were not surfers and did not have a history of surfing for more than ten years.

For both groups, participants were excluded if they: had an existing diagnosis of osteopenia, osteoporosis, or any other medical condition known to affect bone health; had artificial bone implants (such as a hip replacement); had a history of hormone therapy; used any medication that could possibly affect bone density; were a current or past smoker; had a body mass index (BMI) over 30 kg/m^2 or under 21 kg/m^2; or had undergone a radiological examination which requires contrast dye within seven days prior to the study, as perfusion imaging with dye is known to significantly affect BMD results.

All individuals who passed the initial screening were invited to participate in the study. The research took place at the Water Based Research Unit (WBRU), located at the Bond University Institute of Health and Sport (BIHS, Gold Coast, Queensland, Australia). An explanatory statement and informed consent form were given to all participants upon arrival at the WBRU. Prior to providing written informed consent, all participants had the opportunity to ask any questions about the research and any of the testing procedures.

Procedures

At the WBRU, participants had their height and mass measured and then completed two self-administered questionnaires. The bone-specific physical activity questionnaire (BPAQ)[282] quantified the participants' lifetime physical activity of relevance to bone, and it was calculated for current (cBPAQ), past (pBPAQ), and total (tBPAQ) scores. The second survey quantified current calcium intake, utilizing the calcium calculator from the International Osteoporosis Foundation (IOF) website.[283] A third questionnaire assessed their current alcohol intake, family history of osteoporosis, and surfing characteristics (the latter specifically for surfers). Participants then underwent a dual-energy X-ray absorptiometry (DXA) scan at the bone health and body composition (BC) laboratory, for BMD analysis of the non-dominant hip and lumbar spine (LS). Additionally, BC was assessed via a total body scan.

Following the DXA scans, a randomly allocated participant subsample provided a blood sample for analysis of two bone turnover biomarkers: serum carboxy-terminal collagen crosslinks (sCTx) and serum procollagen type 1 N-terminal propeptide (sP1NP). A standard blood test was collected and analyzed by a commercial pathology laboratory (Sullivan Nicolaides Pathology, Gold Coast, Queensland, Australia), for this purpose.

Outcome measures

Height, mass, and body mass index (BMI)

Participants were requested to remove their shirt, slacks, shoes, and socks to enable assessment of their height, which was measured using a stadiometer (Harpenden, Holtain Limited, Crymych, UK) to the nearest 0.01 meter (m). Mass was then measured to the nearest 0.1 kilogram (kg) using a standard digital weighing scale (WM202, Wedderburn, Bilinga, Australia). Body mass index (BMI) was then calculated using the traditional method: BMI = weight/height^2 (kg/m^2).

Physical activity

The BPAQ[282] was used to capture past physical activity of relevance to bone across their whole lifetime, and specific to the previous 12 months. Physical activity was recorded by type and age when they participated, and the number of years they participated were recorded for each type. Information collected was entered into the BPAQ analysis software (freely available for download, http://www.fithdysign.com/BPAQ), generating current (cBPAQ), past (pBPAQ), and total (tBPAQ) physical activity scores (unitless) for each participant.

Calcium

Daily calcium intake was estimated using the IOF dietary questionnaire and the calcium calculator on the IOF website.[283] Results were recorded as percentage of recommended daily intake (%RDI) according to guidelines of Osteoporosis Australia.[10]

Alcohol

Participants were asked about the number of standard (std) drinks they normally consume in a typical week, as excessive amounts of alcohol are known to negatively affect bone health.[76,109]

Body composition, BMD and T-score

A DXA scan (General Electric, GE, Lunar Prodigy, Madison, WI, USA) was conducted for each participant in order to determine the primary outcomes (femur BMD, LS BMD, and T-score) and BC (fat and lean mass). The scanner was calibrated each morning prior to any scans using a manufacturer's 'phantom' (quality assurance and quality control procedures). Prior to all DXA scans, participants were required to complete a short health questionnaire, to determine if for any reason the DXA scan should not take place. To avoid falsely elevated bone density, all metal objects were removed and participants were required to wear only light clothing. Participants were positioned according to the site that was to be measured. For the analysis of the LS, the participant lay supine on the scan bed, centred and straight, ensuring hips and shoulders were square, with the legs flexed over a support pad (supplied by the manufacturer), to create an angle of 60° to 90° between the table top and the participant's thighs. For the analysis of the hip (unilateral, non-dominant side), the participant lay supine with the legs in internal rotation (approximately 15°) and slight abduction. This positioning is important in order to minimize the visibility of the lesser trochanter and to maintain the femoral axis straight. Estimates of BC were obtained from the total body scan. For the total body scan, the participant's head was positioned directly below the horizontal line running across the top of the scan table. The entire participant's body was positioned within the lateral region or interest lines on the table. BC was analyzed to determine percentage of lean mass (%lean mass) and fat mass (%fat mass). Results were analyzed using the commercial software provided with the DXA machine (enCORE software, version 17, GE, Lunar Prodigy, Madison, WI, USA).

The DXA scan yielded BMD (g/cm^2) and T-score of the femur and LS, based on the regions of interest (ROI) recommended by the International Society for Clinical Densitometry (ISCD) official position.[89] The T-score recorded was the lowest result obtained between the two regions and was used to classify the participant according to the World Health Organization (WHO) criteria for the diagnosis of osteoporosis (T-score greater than -1.0 is considered normal, T-score between -1.0 and -2.5 is considered osteopenia, and T-score below -2.5 is considered osteoporosis).[7]

- Intra-tester reliability

Before conducting the study, intra-rater reliability and precision of DXA in evaluating BC and BMD was assessed using a sample of 30 individuals. Assessment of BC and BMD in the LS, femoral neck and total hip yielded measurements with high intra-rater reliability.[285,286]

Surfing group characteristics

Surfers were assessed with regard to surfing specific characteristics, which included: surfing ability, as measured by the Hutt scale[287]; surfing experience in years; number of sessions per month; number of hours per session; surfing exposure (number of hours per session multiplied by number of sessions per month); stance while surfing (ie, 'regular' if left foot forward or 'goofy' if right foot forward); and type of surfboard (short, mini-mal/funboard or longboard).

Biochemical markers of bone turnover

Bone turnover markers sCTx (ng/L) and sP1NP (µg/L) were collected and analyzed via serum blood at a commercial pathology laboratory in a randomized subsample of participants. To date, the best marker for bone resorption is CTx,[92] as it is primarily associated with osteoclastic activity. The best marker for bone formation is P1NP, due to its wide usage and high utility for fracture prediction.[91,92] P1NP also has a shorter response time than other popular bone formation markers.[93] In addition to this, these biomarkers have recently been assessed in older surfers.[51]

Data analysis

Initially, continuous variables were tested for normality by assessing skewness, kurtosis, Q-Q plots, and the Kolmogorov-Smirnov test, and were summarized using means and standard deviations (SD), if normally distributed. Independent samples *t*-tests were performed on normally-distributed variables to assess differences in mean scores between the surfing and control groups, for each of the outcome measures. For non-normally distributed variable where the skewness could not be corrected through transformations, Mann-Whitney-U tests were used to assess differences between the groups for each of the outcome measures. Categorical outcomes, specifically diagnosis of osteopenia or osteoporosis based on the T-score, were summarized using counts (*n*) and percentages (%); Chi-square test of independence was used to assess any difference between groups. Correlation analyses were also conducted between participant characteristics and outcome variables using the parametric Pearson's product-moment correlation, or the non-parametric Spearman's rank order correlation test, depending on the data distributions. The one-way multivariate analysis of variance (MANOVA) was used to determine whether there were any differences between types of physical activity in relation to the continuous primary outcomes. Statistically significant results were followed-up with univariate one-way analysis of variance (ANOVA) for each outcome variable. Multiple regression analyses were used to examine the relationships between BPAQ scores and the outcome variables. When required, a log transformation was performed. The level of significance, alpha, was set *a priori* at 0.05 for all statistical tests. Results are presented as mean ± SD unless otherwise stated. All analyses were performed with SPSS statistical software (Version 25.0 for Windows, SPSS Inc., Chicago IL, 2017).

Results

A total of 104 participants were eligible to participate in the study and were divided into two groups. Group 1 (surfers) consisted of 59 surfers, and group 2 (controls) consisted of 45 controls.

Surfers had a mean surfing experience of 41.2 years (SD ±11.8), surfing on average 16 times per month (mean 16.1 ± 7.3), each session lasting on average 1.7 hours (mean 1.7 ± 0.4), with a mean surfing exposure of 26.9 hours/month (SD ±15.0). Over 80% of the surfers considered themselves to have advanced surfing skills (Hutt rating of 6 or more), 54.2% used a shortboard, and 43% had a 'regular' stance.

Participants' demographic characteristics can be seen in Table 15. Groups were similar (ie, there were no significant differences between them) with regards to most of the demographic characteristics and measures of physical activity, BMD and BC (age, BMI, number of std drinks, calcium %RDI, %fat mass, pBPAQ score, tBPAQ score, femur BMD, LS BMD, and T-score). However, surfers had higher %lean mass (mean difference [MD] +2.57%; 95% confidence interval [CI] 0.05 to 5.09%; *p*=0.046) and lower cBPAQ score (MD -0.967; 95% CI 0.395 to 1.539; *p*=0.001). On average, the lowest T-score was found at the femur for both groups (surfing group mean -0.6 ± 0.8; control group mean -0.7 ± 0.8; *p*=0.506). None of the participants were classified as having osteoporosis, based upon their T-scores; however, 41.3% of all participants were classified as having osteopenia (42.2% controls, 40.7% surfers), with no statistically significant difference between the groups in this regard (χ^2_1 = 0.025, *p*=0.874).

Table 15: Demographic and other characteristics

Characteristics	Surfers (n= 59)		Controls (n=45)		*p*-value
	Mean	SD	Mean	SD	
Age (years)	60.8	7.2	62.5	6.4	0.198
BMI (kg/m^2)	26.0	2.0	25.9	3.5	0.762
Number of std drinks	7.8	6.4	6.6	6.0	0.370
Calcium intake (%RDI)	95.1	34.7	88.0	32.8	0.283
Lean mass (%)	69.8	5.1	67.3	7.2	0.046*
Fat mass (%)	27.3	5.4	29.8	7.4	0.067
cBPAQ score	0.551	0.101	1.518	1.903	0.001*
pBPAQ score	57.629	36.018	76.553	69.730	0.102
tBPAQ score	29.092	18.008	39.755	34.253	0.620
Femur BMD (g/cm^2)	0.971	0.123	0.971	0.109	0.987
LS BMD (g/cm^2)	1.243	0.107	1.203	0.114	0.087
T-score	-0.7	0.8	-0.8	0.8	0.524

Notes: (*) denotes statistically significant difference between surfer and control groups (p<0.05, 2-tailed). **Abbreviations:** SD, standard deviation; Kg, kilograms; m, meters; std, standard; %RDI, percentage of the recommended daily intake; cBPAQ, current bone-specific physical activity questionnaire score; pBPAQ, past bone-specific physical activity questionnaire score; tBPAQ, total bone-specific physical activity questionnaire score; BMD, bone mineral density; LS, lumbar spine; g, grams; cm, centimeter.

No correlations were found between the primary outcomes (femur BMD, LS BMD, and T-score) and the demographic characteristics age, calcium intake (%RDI), and number of standard drinks. Likewise, surfing-specific characteristics (surfing ability, surfing experience, number of sessions per month, number of hours per session, surfing exposure, surfing stance, and type of surfboard) were not significantly associated with the primary outcomes. The relationships between scores on the BPAQ components and the outcomes BMD and T-score are shown in Table 16. For the surfing group, significant small positive relationships were found between femur BMD and both pBPAQ and tBPAQ scores (*r* 0.299, *p*<0.05 and *r* 0.299, *p*<0.05, respectively), and significant moderate positive relationships were found between T-score and both pBPAQ and tBPAQ scores (*r* 0.326, *p*<0.05 and *r* 0.326, *p*<0.05, respectively), but not between LS BMD and any of the components of the BPAQ. There was no statistically significant correlation between cBPAQ scores and the outcomes in surfers. When both groups were analyzed in combination, significant moderate positive relationships were found between femur BMD and both pBPAQ and tBPAQ scores (*r* 0.386, *p*<0.01 and *r* 0.385, *p*<0.01, respectively), and also between T-score and both pBPAQ and tBPAQ scores (*r* 0.430 *p*<0.01 and *r* 0.436, *p*<0.01, respectively). Similarly, a small positive relationship was found between LS BMD and both pBPAQ and tBPAQ scores (*r* 0.209 *p*<0.05 and *r* 0.221, *p*<0.05, respectively). By contrast, cBPAQ scores did not correlate with the primary outcomes when all participants were analyzed together.

Table 16: Correlations between scores from BPAQ components and the outcomes femur BMD, LS BMD, and T-score

OUTCOMES	Surfers (*n*=59)			Controls (*n*=45)			All participants (*n*=104)		
	cBPAQ	pBPAQ	tBPAQ	cBPAQ	pBPAQ	tBPAQ	cBPAQ	pBPAQ	tBPAQ
Femur BMD (g/cm^2)	0.017	0.299*	0.299*	0.343*	0.419**	0.422**	0.170	0.386**	0.385**
LS BMD (g/cm^2)	-0.051	0.167	0.167	0.296	0.307	0.329*	-0.040	0.209*	0.221*
T-score	-0.034	0.326*	0.326*	0.476**	0.433**	0.439**	0.190	0.430**	0.436**

Notes: Pearson's correlation used; (*) correlation is significant at the 0.05 level (2-tailed); (**) correlation is significant at the 0.01 level (2-tailed). **Abbreviations:** BPAQ, bone-specific physical activity questionnaire; BMD, bone mineral density; LS, lumbar spine; cBPAQ, current BPAQ score; pBPAQ, past BPAQ score; tBPAQ, total BPAQ score; g, grams; cm, centimeter.

The control group was composed of physically active individuals. Walking was the most common exercise (15 individuals), followed by cycling (14 individuals), running (8 individuals), swimming (3 individuals), resistance training (3 individuals), soccer (1 individual), and triathlon (1 individual). Participants were grouped according to their main current physical activity into three groups: surfing (*n*=59), non-weight-bearing/low intensity (NWBLI, *n*=32), and weight-bearing/high intensity (WBHI, *n*=13) as shown in Table 17.

Table 17: Participants' main current physical activity

Physical activity	N	Group
Surfing	59	Surfing (*n*=59)
Swimming	3	NWBLI (*n*=32)
Cycling	14	
Walking	15	
Resistance training	3	WBHI (*n*=13)
Running	8	
Soccer	1	
Triathlon	1	
Total	104	104

Abbreviations: N, number of individuals; NWBLI, non-weight-bearing/low intensity; WBHI, weight-bearing/high intensity.

A Chi-square test of independence was conducted to examine the relationship between type of physical activity (surfing, WBHI, and NWBLI) and diagnosis of osteopenia based on the participants' T-score. There was a statistically significant association between type of physical activity and diagnosis of osteopenia (χ^2_2 = 13.464, *p*=0.001). The association was moderately strong, Cramer's V = 0.36.[288] The group NWBLI had the highest prevalence of osteopenia (59.4%) when compared to surfing (40.7%) and WBHI (0%). A one-way MANOVA was conducted to determine if the dependent variables femur BMD, LS BMD, and T-score were different for the three different types of physical activity (surfing, WBHI, and NWBLI). Descriptive statistics summarizing the results for each of the primary outcomes in the physical activity groups are shown in Table 18.

Table 18: Primary outcomes by type of physical activity

Outcome	Type of physical activity	Mean	SD
Femur BMD (g/cm^2)	NWBLI	0.930	0.090
	WBHI	1.044	0.106
	Surfing	0.969	0.123
LS BMD (g/cm^2)	NWBLI	1.179	0.113
	WBHI	1.260	0.099
	Surfing	1.243	0.107
T-score	NWBLI	-1.1	0.7
	WBHI	-0.2	0.6
	Surfing	-0.7	0.8

Abbreviations: SD, standard deviation; BMD, bone mineral density; LS, lumbar spine; g, grams; cm, centimeter; NWBLI, non-weight-bearing/low intensity; WBHI, weight-bearing/high intensity

There were statistically significant differences between the groups reflecting type of physical activity in the combined dependent variables (femur BMD, LS BMD, and T-score), $F(6, 188) = 3.124$, $p = 0.006$; Pillai's Trace = 0.18; partial $\eta^2 = 0.091$. Follow-up univariate ANOVAs showed that femur BMD ($F(2, 95) = 4.310$, $p = 0.016$; partial $\eta^2 = 0.083$), LS BMD ($F(2, 95) = 3.960$, $p = 0.022$; partial $\eta^2 = 0.077$), and T-score ($F(2, 95) = 7.40$, $p = 0.001$; partial $\eta^2 = 0.135$) all differed significantly between the different physical activity groups. The primary outcomes improved from the NWBLI group to surfing, and from surfing to WBHI group, in that order.

Games-Howell post-hoc tests showed that for femur BMD, the WBHI group had a significantly higher mean than the NWBLI group (MD +0.114; 95% CI 0.025 to 0.203; p=0.011); however, no differences were found between the WBHI and surfing groups or between the surfing and NWBLI groups. For LS BMD, surfers had a significantly higher mean than the NWBLI group (MD +0.064; 95% CI 0.002 to 0.126; p=0.041), but no differences were found between surfing and WBHI or between WBHI and NWBLI. Lastly, for T-score, the WBHI group had a significantly higher mean than the NWBLI group (MD +0.918; 95% CI 0.389 to 1.446; *p*=0.001) and surfing (MD +0.516; 95% CI 0.024 to 1.009; *p*=0.039), and surfers had a significantly higher mean than the NWBLI group (MD +0.401; 95% CI 0.012 to 0.791; *p*=0.042). Mean differences and 95% CI are shown in Table 19.

Table 19: One-way MANOVA post-hoc analyses: mean differences in outcomes between activity types

Outcomes	Types of physical activities compared		Mean difference	*p*-value	95% Confidence Interval	
					Lower	Upper
Femur BMD (g/cm^2)	WBHI	NWBLI	0.114*	0.011	0.025	0.203
		Surfing	0.075	NS	-0.014	0.162
	Surfing	NWBLI	0.039	NS	-0.017	0.095
		WBHI	-0.075	NS	-0.163	0.014
LS BMD (g/cm^2)	WBHI	NWBLI	0.081	NS	-0.009	0.170
		Surfing	0.017	NS	-0.065	0.099
	Surfing	NWBLI	0.064*	0.041	0.002	0.126
		WBHI	-0.017	NS	-0.099	0.065
T-score	WBHI	NWBLI	0.918*	0.001	0.389	1.446
		Surfing	0.516*	0.039	0.024	1.009
	Surfing	NWBLI	0.401*	0.042	0.012	0.791
		WBHI	-0.516*	0.039	-1.009	-0.024

Notes: Based on observed means; Games-Howell post-hoc test used; (*) the mean difference is significant at the 0.05 level. **Abbreviations:** MANOVA, multivariate analysis of variance; BMD, bone mineral density; LS, lumbar spine; g, grams; cm, centimeter; WBHI, weight-bearing/high intensity; NWBLI, non-weight-bearing/low intensity.

Multiple regression analyses were run to predict the primary outcomes from the cBPAQ, pBPAQ, and tBPAQ scores. The components of the BPAQ statistically significantly predicted T-score (F [3, 100] = 8.048, p < 0.0005) and femur BMD (F [3, 100] = 5.688, p = 0.001), but not LS BMD (F [3, 94] = 2.036, p = 0.114). For T-score, the R^2 value for the overall model was 19.4% with an adjusted R^2 of 17.0%, and for femur BMD the R^2 value for the overall model was 14.6% with an adjusted R^2 of 12.0%. Predictions were made to determine an average score required for each of the components of the BPAQ in order to result in a T-score within the lower bound of the normal range. Results revealed that a cBPAQ score of 0.969, a pBPAQ score of 68.817, and a tBPAQ of 33.705 would result in a mean T-score of -0.7 (95% CI, -0.8 to -0.6). A hierarchical multiple regression was run to determine whether the addition of %lean mass and type of physical activity improved the prediction of the primary outcomes over and above the components of BPAQ. Neither of these additional predictors led to a statistically significant improvement in predicting femur BMD, LS BMD, or T-score (p > 0.05).

A randomized sample of 20 individuals, 10 in each group, was selected for analysis of serum biomarkers of bone turnover (CTx and P1NP). The mean results for both groups were within normal range for both CTx and P1NP, with no significant difference between groups (Table 20).

Table 20: Biochemical markers of bone turnover, mean and SD values by group

Biomarker	Surfers (n= 10)		Controls (n=10)		P value
	Mean	SD	Mean	SD	
P1NP (µg/L)	47.6	20.3	49.6	13.2	0.797
CTx value (ng/L)	384	200.0	400	203.3	0.861

Notes: P1NP normal range: 15-80 ug/L; CTx normal range: 100-600 ng/L. **Abbreviations:** SD, standard deviation; P1NP, procollagen type 1 N-terminal propeptide; CTx, C-telopeptide cross-link of type 1 collagen.

Discussion

The primary goal of the present study was to assess the bone health of middle-aged and older male surfers and to compare the results with those from a control group comprised of age- and sex-matched active non-surfer individuals. To the best of our knowledge, this is the first study to investigate the bone health of middle-aged and older surfers by assessing the traditional clinical BMD sites (femur and LS), as recommended by the WHO[7] and ISCD.[89] The main findings of the present study support the hypothesis that surfing is associated with reduced age-related bone deterioration, as we identified positive results for surfers in relation to our primary outcomes (femur BMD, LS BMD, and T-score).

A strong relationship between exercise and bone health has been reported in the literature; however, different modalities of exercise have different effects on bone health. To date, the sport of surfing has not been adequately investigated in relation to its association with age-related bone loss. To address this gap, we recruited and compared a group of middle-aged and older surfers and a group of physically active individuals, who were non-surfers and age- and sex-matched, as controls. Demographic characteristics (Table 15) were similar between the groups, except for %lean mass and cBPAQ score. The cBPAQ score obtained from surfers was approximately one-third of the score obtained from individuals in the control group. This was expected as, consistent with our inclusion criteria, surfers included in the study could not be involved in any other type of physical activity. Additionally, surfing only receives a small score in the BPAQ, due to its relatively small peak ground reaction force (GRF). This may explain the smaller scores (although not significantly different) obtained by surfers in the pBPAQ and tBPAQ when compared to control participants, as surfing was the main physical activity for the majority of the surfers during their lifetime.

Individuals in the control group were engaged in different exercise modalities, and these activities were grouped based on their weight-bearing/intensity characteristics in two different groups: non-weight-bearing/low intensity (NWBLI; eg, swimming, cycling, and walking) and weight-bearing/high intensity (WBHI; eg, resistance training, running, soccer, triathlon) (Table 17). The NWBLI group had the lowest values for all three primary outcomes (Table 18). Additionally, surfers had significantly higher LS BMD and T-scores when compared to the NWBLI group; however, surfers had a lower mean T-score than the WBHI group (Table 19).

The current study found a prevalence of osteopenia of 41.3%, with no difference between surfing and control groups. This prevalence rate is lower than that previously reported for Australians, which was 55% for men.[289] However, this difference is likely to be mainly due to the exclusion of men with known osteopenia or osteoporosis from the study, so they would not have responded to invitations to participate if they knew they suffered from one of these conditions and understood it was an exclusion criterion. The same guidelines reported a prevalence of 3% of osteoporosis in men; however, none of the individuals in our study met the diagnostic criteria for osteoporosis, though this again might be due to the exclusion of men with known osteoporosis from participation in the study. It is nevertheless possible that these differences in prevalence of osteopenia and osteoporosis may also in part be explained by the fact that all participants in our study were physically active, particularly given that osteoporosis and osteopenia are often undiagnosed and so some participants would conceivably not have known they had it at the time they volunteered to participate and would, therefore, still have been recruited. When results of the present study were analyzed according to the type of physical activity (ie surfing, NWBLI, and WBHI), the surfing group had a prevalence of osteopenia of 40.7%, almost 20% lower than that for the NWBLI group ($\chi^2(2) = 13.464$, p=0.001), and nearly 15% lower than that previously reported in the literature.[289] This difference cannot be explained by the study exclusion criteria, since all participants, in both groups, were subject to those criteria.

With regard to BPAQ scores, when all participants were analyzed in combination, pBPAQ and tBPAQ scores were correlated to the primary outcomes (Table 16); however, no association was found between the outcomes and cBPAQ scores. When only the surfing group was analyzed, there was no correlation between scores on the three components of the BPAQ and LS BMD, but there was correlation between pBPAQ and tBPAQ scores and both femur BMD (small correlation) and T-score (moderate correlation). For the control group, there was a moderate correlation between all components of the BPAQ and the primary outcomes, except for between cBPAQ and pBPAQ scores and LS BMD. Similar findings were reported by Bolam et al.,[290] who analyzed a group of healthy middle-aged and older men and reported moderate correlations between scores on the three components of the BPAQ and femoral neck BMD; however, the authors did not find a significant correlation between BPAQ scores and LS BMD.

On average, surfers had over 40 years of experience in the sport, with more than 25 hours per month of surfing exposure. These characteristics are in line with the findings of the previous study in surfers.[51] The main difference is the type of board used by the participants. In the present study, more than 54% of the individuals used a shortboard, which is associated with a more dynamic performance, whereas all surfers in the previous study were longboarders. Even though surfing characteristics were not correlated with our primary outcomes, increased neuromuscular activation, associated with muscle force production, in order to control movements and posture during the different physical demands associated with the sport, may be considered important contributors to the positive findings revealed by our analyses in the surfing group. Based on the results for the primary outcomes in the surfing group, it seems that the BPAQ may not accurately score the impact of the sport on bone health. This can be illustrated by the relatively low mean scores for the surfing group for all three components of the BPAQ (Table 15).

In the analysis of biochemical markers of bone turnover, we were able to include 20 participants in the analyses – 10 surfers and 10 controls. We failed to find a significant difference between the groups, most likely due to the small sample size, and therefore no assumptions can be made on this basis.

The main strength of this study is its eligibility criteria, allowing better control of confounding factors (eg, medical conditions and medications known to affect BMD, smoking status, calcium, and alcohol intake, very low or very high BMI) that could potentially interfere with the results. However, limitations should be highlighted. Firstly, the study design does not allow us to infer cause and effect; secondly the sample size was small, due to the strict eligibility criteria; lastly, we did not assess vitamin D, due to budget limitations. Therefore, findings of the present study should be interpreted with caution and cannot be extrapolated to all individuals.

Conclusion

The purpose of the current study was to determine the bone health of middle-aged and older surfers. Results were compared to those for a physically active, age- and sex-matched control group. Surfers have statistically higher BMD at the LS and higher T-scores when compared to individuals engaged in non-weight-bearing/low impact physical activities. Overall, this study strengthens the idea that surfing might be an effective exercise to decrease the rate of bone loss associated with aging. A natural progression of this work is to conduct a longitudinal analysis of the bone health in this population.

Chapter 6: Auditory exostoses of the external ear canal: "a case of Surfer's Ear".

Preface

This chapter is the first part of the second major focus of this thesis: the bone health of the external auditory canal (EAC).

Auditory exostosis, commonly known as surfer's ear, is a common clinical complication related to surfing. However, as detailed in Chapter 2, gaps in research on this issue exist. While auditory exostosis has been perceived to be primarily associated with cold-water surfing, no studies were found in surfers exclusively exposed to warm-water. Additionally, with regards to prevalence, disparities in results are found when studies reporting prevalence via otoscopic examination (for otoscopic examination procedure see https://www.youtube.com/watch?v=7R7lKEVBFaQ) are compared to self-reported prevalence obtained via online survey.

Therefore, the present chapter explores the current knowledge about exostosis of the auditory canal (EAE), using a case study approach and detailing the condition in a questions-and-answers format. This chapter was published in the Australian Family Physician journal, and the published version is found in Appendix VIII. The chapter is formatted according to the journal's guidelines.

***Simas V**, Furness J, Hing W, Pope R, Walsh J, Climstein M. Ear discomfort in a competitive surfer. Aust Fam Physician. 2016 Sep;45(9):644-6.*

Ear discomfort in a competitive surfer: the case

A previously healthy, competitive surfer (male, aged 23 years) from the Gold Coast presented with chronic ear discomfort, having noticed frequent water trapping in the ear canal (Figure 32). He had been surfing for 11 years and denied participating in any other form of water activity.

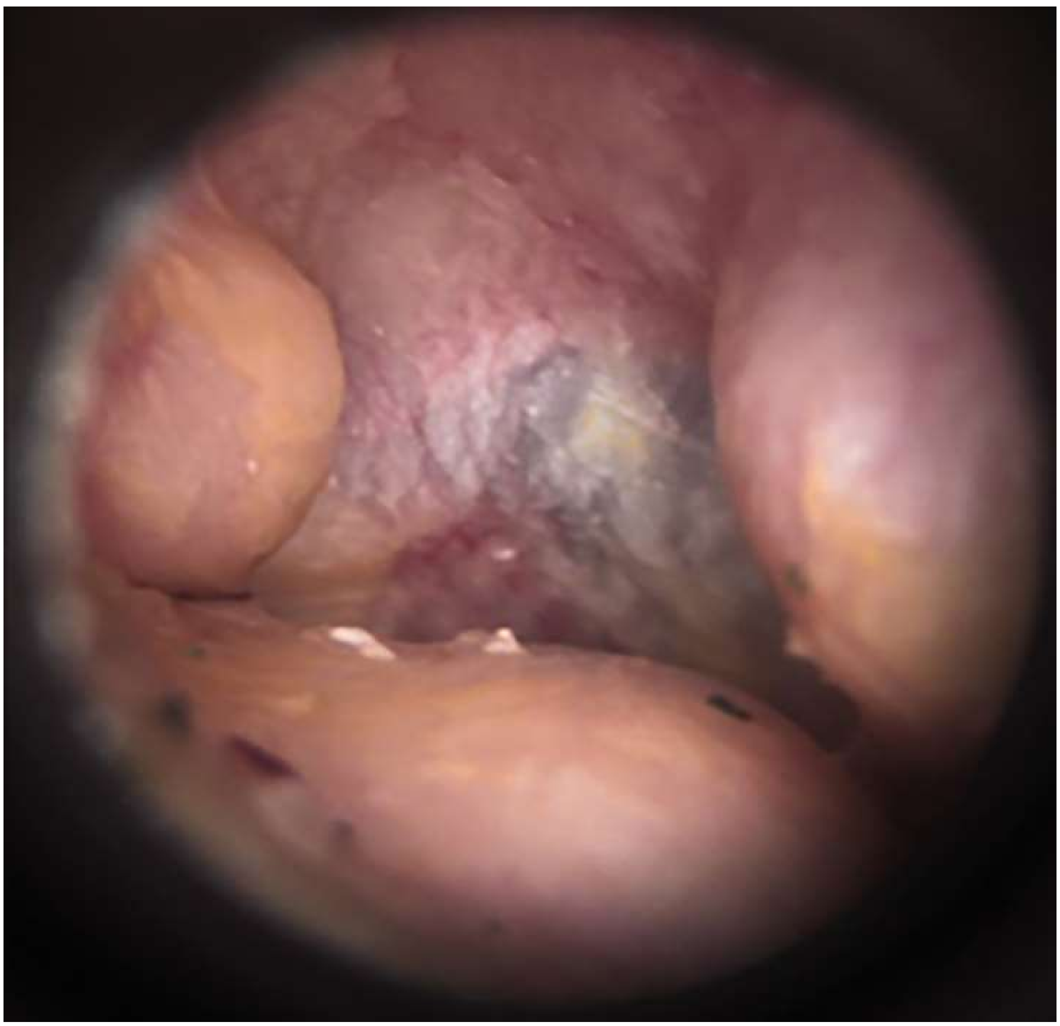


Figure 32: Otoscopic image identifying auditory exostoses in a young male competitive surfer

What is surfer's ear?

Surfing is a popular recreational activity and competitive sport, with an estimated 37 million surfers worldwide.[44] In Australia, this number is estimated at 2.7 million, which accounts for more than one in 10 Australians.[46] One of the chronic conditions associated with surfing is external auditory exostosis (EAE). This condition is a benign and irreversible, broad-based bone outgrowth that arises from the temporal bone and projects into the external auditory canal (EAC). EAE is commonly referred to as surfer's ear, although it has also been described in other aquatic sports. Australia is recognized as having a high prevalence of EAE.[64,174,175]

What is the clinical presentation of surfer's ear?

Typically found bilaterally with multiple lesions, EAE is usually asymptomatic and hence is often diagnosed when the condition is at an advanced stage,[168] leading to a higher incidence of potentially serious health issues. Patients can present with a prolonged blocked feeling in the ears following water activities because of water trapping in the EAC or chronic cerumen impaction. Patients may also present with recurrent otitis externa, otalgia and conductive hearing impairment due to stenosis of the EAC.

EAE can be classified into four grades of severity based on the percentage of obstruction of the EAC, as assessed by otoscopy (Figure 33)[173]:

- Grade 0 – normal ear canal, no visible exostosis
- Grade 1 – obstruction of up to 33%
- Grade 2 – obstruction of 34–66%
- Grade 3 – obstruction of 67–100%.

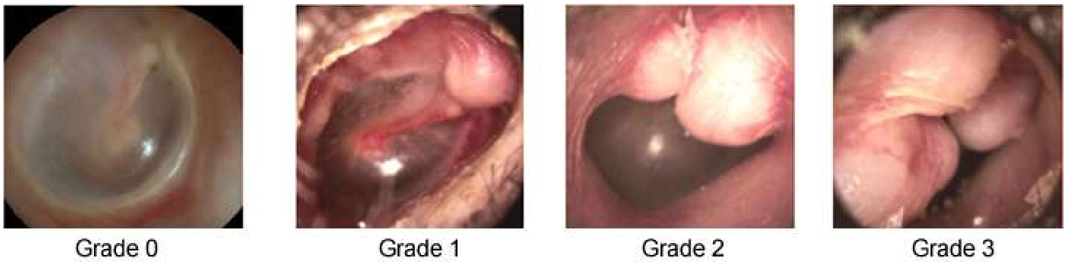


Figure 33: Otoscopic image identifying the four grades of EAE

What is the prevalence of surfer's ear in surfers?

The prevalence of this condition in surfers, both professional and recreational, is 38–80% when investigated by otological examination.[58,169] A study in Victoria reported that 78% of male surfers and 69% of female surfers had some degree of exostoses; a severe grade (ie Grade 3) was observed in more than 50% of the male surfers diagnosed.[64] However, our recent study investigating injuries while surfing via an online survey identified only 3.5% of the participants reporting exostoses.[65]

What are the pathophysiology and etiology of surfer's ear?

The precise mechanism for the development of EAE remains unknown. Cold water and air exposure are believed to stimulate osteoblasts within the temporal bone, leading to bone growth into the EAC, possibly as a mechanism to protect the tympanic membrane against low temperatures.[178,183]

What are the risk factors of surfer's ear?

It is well known that EAE is highly correlated with the amount of time spent in the water. The risk of EAE increases after five sessions of surfing per month and significantly increases after five years of surfing.[54,179] Exposure to cold water and wind are recognized risk factors.[62,63] With regard to the wind effect, it has been proposed that evaporative cooling would result in greater progression of exostoses in the ear more exposed to a predominant wind. However, some studies did not find significant differences in prevalence and severity between the ears, even though one ear was typically more exposed to the wind than the other.[178] Exostosis of the EAC does not appear to be influenced by genetic factors or any type of medication.[177,178]

How is surfer's ear diagnosed?

Auditory exostosis is diagnosed via otoscopic examination to identify bony outgrowths projecting into the EAC.

What are the differential diagnoses of someone suspected of having surfer's ear?

Some of the differential diagnoses of EAE include osteoma, squamous cell/glandular cell carcinoma, benign glandular tumors, cholesteatoma and conditions affecting the temporal bone (eg, paraganglioma).[292]

Is surfer's ear preventable?

The feasibility of EAE prevention remains uninvestigated. However, given the current theory of etiology, the regular use of earplugs or other protective equipment (eg, hood) has been suggested in the literature to prevent the occurrence of EAE.[179] Avoiding exposure to cold or windy conditions when surfing is also recommended.

What is the treatment of surfer's ear?

The definitive treatment of EAE is surgical removal, which is usually only reserved for severe and symptomatic cases. This procedure does not prevent recurrence and exposes the individual to risk of complications, such as tympanic membrane rupture, sensorineural hearing loss, facial nerve injury, infection, delayed healing and stenosis.[62,174]

When is it appropriate to refer a patient with surfer's ear to a specialist?

Referral to an otorhinolaryngologist is advised for large lesions (Grade 3), recurrent ear infections or progressive hearing loss. Referral is also recommended if the doctor or patient have any concerns, and when there is suspicion of another diagnosis (eg, tumor) or when the symptoms are not compatible with clinical findings (eg, hearing loss with only a small lesion). An audiogram should be organized prior to referral.[292]

Key points

- EAE is a common condition in surfers.
- EAE is typically undiagnosed at early stages.
- EAE is a potentially serious health issue.
- Risk factors of EAE include exposure to cold water and wind.
- The only treatment for EAE is surgical correction, which is reserved for severe or symptomatic cases.
- Prevention of EAE should be highlighted, and general practitioners play an important role in early identification and advising susceptible patients.

Chapter 7: Auditory exostoses in Australian warm water surfers: prevalence, risk factors, and severity.

Preface

This chapter continues to explore the bone health of the external auditory canal (EAC). It relates to the specific objective of this body of research to analyze the prevalence and severity of external auditory exostoses (EAE) in warm-water surfers.

In Chapter 2, a gap in the literature reflecting a lack of studies assessing the EAC of surfers exclusively exposed to water temperatures above 19^{o}C was evident. Therefore, this chapter reports the results of a cross-sectional observational study assessing the EAC of surfers who were exclusively exposed to warm waters, in order to assess prevalence and severity of EAE.

The results of the present chapter were submitted for publication as two different manuscripts. The first manuscript, *The Prevalence and Severity of External Auditory Exostosis in Young to Quadragenarian-Aged Warm-Water Surfers: A Preliminary Study*, was published in the journal Sports, and the published version is found in Appendix IX. The second, *Auditory exostosis in Australian warm water surfers: prevalence and severity*, is currently under review.

Simas V*, Hing W, Furness J, Walsh J, Climstein M. The Prevalence and Severity of External Auditory Exostosis in Young to Quadragenarian-Aged Warm-Water Surfers: A Preliminary Study. Sports (Basel). 2020 Feb 4;8(2). pii: E17. doi: 10.3390/sports8020017.* This is an Open Access article reproduced under the permission of the Creative Commons Attribution Non-Commercial (CC BY-NC 4.0) license.

Simas V*, Hing W, Rathbone E, Pope R, Climstein M. Auditory exostosis in Australian warm water surfers: prevalence and severity. (Under review).*

Abstract

Purpose

This study aimed to assess the prevalence and severity of external auditory exostosis (EAE) in warm water surfers.

Patients and methods

A cross-sectional observational design was employed, assessing surfers living and surfing on the Gold Coast (Queensland, Australia), where the water temperature ranges from 19 to 22°C in August (winter), to between 26 and 28°C in February (summer). Currently active surfers over 18 years of age, surfing year-round, with a minimum of five consecutive years of surfing experience were recruited to participate. Individuals who successfully passed the initial screening were asked to complete a questionnaire detailing basic demographic data, surfing habits, and otological history. After completing the questionnaire, all volunteers underwent bilateral otoscopic examination, in order to assess the presence and severity of EAE.

Results

A total of 85 surfers were included in the study, with mean age 52.1 years (standard deviation [SD] ±12.6 years) and mean surfing experience of 35.5 years (SD ±14.7 years). Nearly two-thirds of participants (65.9%) had regular otological symptoms, most commonly water trapping (66%), hearing loss (48.2%), and cerumen impaction (35.7%). Less than one-fifth of the surfers (17.7%) reported regular use of protective equipment for EAE (eg, ear plugs). The overall prevalence of exostosis was 71.8%, with the majority of the individuals having bilateral lesions (59%) and a mild grade (grade 1, 47.5%). There was insufficient evidence for any significant associations between the main outcomes (presence and severity of EAE) and factors related to age, surfing experience, winter exposure, surfing ability, symptoms, and use of protective equipment.

Conclusion

To the best of our knowledge, this is the first study assessing EAE in surfers exposed to warm waters (above 19°C). The prevalence of 71.8%

highlights the high prevalence of the condition in the surfing population, regardless of water temperature. Future research should focus on ways to prevent EAE.

Keywords

Auditory exostoses; Surfing; Surfer's ear; Otology; Preventive medicine; Sports medicine

Introduction

Surfing is a popular sport in Australia, with the estimated number of participants over 2.5 million, accounting for nearly 10 percent of the nation's population.[46] Exostosis of the external auditory canal (EAC), also referred to as surfer's ear, is recognized as a potentially serious complication of surfing.[52,293] Commonly multiple and found bilaterally, external auditory exostosis (EAE) is an irreversible benign condition. Exostosis can be associated with a variety of clinical features, including an intermittent blocked feeling of the EAC, especially after water exposure, recurrent cerumen blockage, frequent ear infections, pain in the EAC, and hearing deterioration due to the obstructive nature of the condition.[293]

The pathophysiology and prevention of EAE remain unclear. The consistent use of protective equipment, such as earplugs and hoods, has been proposed to prevent its occurrence and is advised;[179,184] however, the efficacy of these preventative measures remains to be established. Surgery is the only treatment, and it is usually reserved for patients with severe and symptomatic cases; however, the surgical procedure does not prevent recurrence.[62,174]

It is well acknowledged that there is a positive association between the amount of time spent surfing and the presence and severity of EAE, with risk increasing after only five sessions per month and significantly increasing after five years surfing.[54,179] Regarding the relationship between EAE and water temperature, cold water (water temperature below 19ºC) is a commonly cited risk factor, with prevalence of EAE in cold water surfers ranging from 61 to 80 percent.[58,64,169-173,178,180] Additionally, anthropological data indicate that regions located more than 30º north or south of the equator line, where the annual average water temperature is below 19ºC, have a high prevalence of EAE.[180] Nevertheless, there is a paucity of studies reporting the prevalence of EAE in surfers exposed to water temperatures above 19ºC.

Located at 28º south of the equator, the Gold Coast region of Australia is world-famous for its surf breaks, with mean water temperature ranging from 19 to 22°C in August (winter), through to 26 to 28°C in February (summer).[182] It thus provides the ideal environment in which to address the main goal of this study: to assess the prevalence and severity of EAE in warm water surfers.

Methods

Study design

This research used a cross-sectional observational design. The study was approved by the Bond University Human Research Ethics Committee (BUHREC 15221).

Participants

Surfers were recruited through advertising in a local paper and from local boardrider clubs in the Gold Coast (GC) area (City of Gold Coast, Queensland, Australia). Additional support for recruitment was obtained from surfing magazines, websites and local surf shops in the GC area.

Eligibility criteria

Only individuals living and surfing in the GC region were considered to be included. Currently active surfers over 18 years of age, surfing all year round, with a minimum of 5 consecutive years of surfing experience, surfing at least five sessions per month, were invited to take part in the research. Surfers were excluded from the study if they had a history of exposure to cold water (mean temperature below 19°C) for more than 3 consecutive weeks, if they participated for more than 3 consecutive weeks in winter sports activities (eg, skiing, snowboarding), or if they have lived in cold regions (located more than 30° north or south of the equator) for more than 5 consecutive years in their lifetime. Additionally, participants were excluded if both the right and left EAC were occluded by cerumen.

Procedures

All participants who successfully passed the initial screening were invited to participate in this study. The research took place at the Water Based Research Unit (WBRU), Bond Institute of Health and Sport, Bond University, Gold Coast (Queensland, Australia). An explanatory statement and consent form were given to all participants upon arrival at the WBRU. Prior to providing written informed consent, all potential participants were given the opportunity to ask any questions about the research and about the testing procedure. The explanatory statement illustrated the exam to be conducted, and also contained a simple overview of the research project and its purpose. The consent form was signed once participants were satisfied with the information provided.

At the WBRU, participants were asked to complete a questionnaire to collect basic demographic data and to examine their surfing habits and otological history. After completing the questionnaire, all participants underwent clinical examination of both ears, via otoscopy, by an experienced Sport and Exercise Physician, using a hand-held, battery-powered digital otoscope (Digital MacroView™, Welch Allyn®, USA), capable of acquiring digital images.

Predictors and outcome measures

Surfing characteristics

Surfers were assessed with regard to surfing specific characteristics, which included: surfing experience in years; average number of sessions per week; average number of hours per session; winter exposure in hours (number of hours per session during winter multiplied by number of sessions during winter and number of years surfing); surfing ability, as measured by the Hutt scale;[287] stance while surfing (ie 'regular' if left foot forward or 'goofy' if right foot forward); and main type of surfboard (short, mini-mal/funboard or longboard). Additionally, they were asked whether they were involved in any other ocean sport.

Otological history

Participants were asked about the presence of otological symptoms (eg, otalgia, hearing loss), regular use of prevention methods for EAE (eg, ear plug, hood), and previous history of otitis externa (OE) and EAE.

Exostosis

During otoscopy, images of the EAC were recorded, and all images were assessed to determine the presence of EAE. If present, the degree of obstruction of the EAC was graded on the standard clinical one-to-three scale (Figure 34; grade 1: up to 33% of obstruction; grade 2: between 34% to 66% of obstruction; grade 3: more than 67% of obstruction), as previously described.[173]

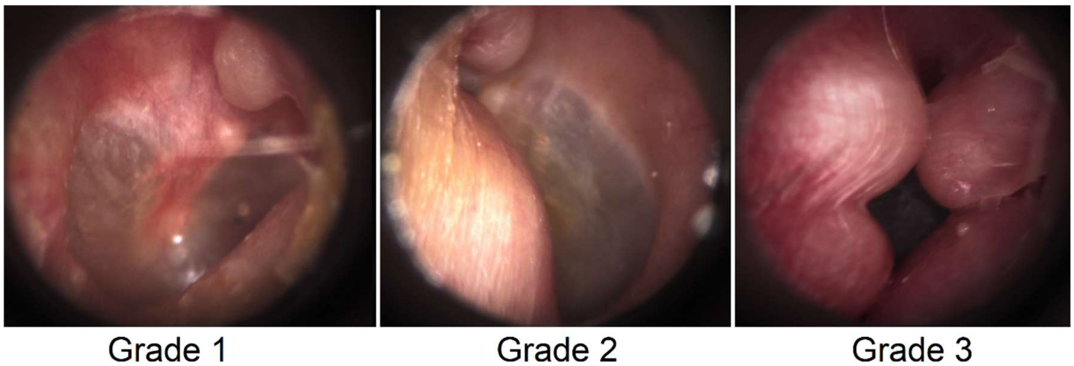


Figure 34: Exostosis severity

Notes: Grade 1: up to 33% of obstruction of the external auditory canal (EAC); Grade 2: between 34% and 66% of obstruction of the EAC; Grade 3: more than 67% of obstruction of the EAC.

Data analysis

Continuous data were analyzed descriptively to determine means and standard deviations (SD) and tested for normality by assessing skewness, kurtosis, Q-Q plots, and the Kolmogorov-Smirnov test. Categorical outcomes were summarised using frequencies and percentages. A Chi-square test of independence was used to assess associations between the main outcome variables (EAE presence and severity) and categorical outcomes. The level of significance, alpha, was set *a priori* at 0.05 for all statistical tests. All analyses were performed with SPSS statistical software (Version 25.0 for Windows, SPSS Inc., Chicago IL, 2017).

Results

A total of 85 surfers were eligible to take part in our study (eighty-one males, 95.3%), with a mean age of 52.1 years (SD ±12.6). Participants had a mean surfing experience of 35.5 years (SD ±14.7), surfing on average 3.8 times per week (SD ±1.8), and each session having a mean duration of 1.7 hours (SD ±0.5). Age, surfing experience, winter exposure, and surfing ability were grouped in categories, and these are shown in Table 21. The majority of the individuals had a regular stance (left foot forward, 78.8%) and used a shortboard (72.9%) as the main type of surfboard. Nearly half of the participants (49.4%) were regularly involved in other ocean sports, most commonly swimming (17.6%) and stand-up paddle boarding (12.9%).

With regards to otological history, almost two-thirds of the surfers (65.9%) reported having regular symptoms and, of these, 62.5% had two or more symptoms. The most common complaint was water trapping (66%), followed by hearing loss (48.2%) and cerumen impaction (35.7%). Despite the high prevalence of otologic symptomatology, less than one-fifth of the participants (15 individuals) reported regular use of prevention methods. Earplugs (n=5), alcohol-based ear drops (n=5), and hoods (n=2) were the preventive methods employed by the surfers. Three individuals used a combination of these three methods. Thirty-five surfers (41.2%) reported ear infection in the past, and 20 (23.5%) reported having EAE diagnosed by either their General Practitioner (GP) or a specialist, with four of these surfers (20%) having had previous surgical removal of exostosis.

Table 21: Demographic characteristics

Characteristics	N	Percent
Age		
- 18 to 30 years	6	7.1%
- 31 to 50 years	28	32.9%
- 51 to 75 years	51	60%
Surfing experience		
- Less than 10 years	6	7.1%
- 11 to 25 years	20	23.5%
- 26 to 50 years	46	54.1%
- More than 50 years	13	15.3%
Winter exposure		
- Less than 1500 hours	35	41.2%
- 1500 to 3000 hours	24	28.2%
- More than 3000 hours	26	30.6%
Surfing ability (Hutt scale[287])		
- Beginner	2	2.4%
- Intermediate	57	67.1%
- Advanced	26	30.6%

Abbreviation: N, number of individuals.

Some degree of exostosis (grade 1 to 3, inclusive) was present in 61 individuals (71.8%, Figure 35), of which 36 (59%) had bilateral lesions, with similar prevalence in left and right sides (56.5% and 57.6%, respectively, no significant difference). With regards to severity (Figure 36), nearly half of the individuals with EAE had only a minor grade of EAE (grade 1, 47.5%), 22.4% had grade 2, and only 15.3% were classified as having a severe grade of EAE (grade 3).

A Chi-square test of independence was used to analyze the association between the presence of EAE and the following predictor variables: age group, surfing experience group, winter exposure group, surfing ability group, participation in other ocean sports, presence of otological symptoms, use of protective equipment, and previous history of OE. Surprisingly, there was no correlation between any of the predictor variables and the outcome. Additionally, a Chi-square test of independence was also used to analyze the relationship between the same predictors and the severity of EAE, again with no statistically significant results. However, when analyzing associations between predictor variables and potential cofounding factors, there was a statistically significant association between the presence of hearing loss and age, $\chi2(1) = 3.901$, $p=0.048$.

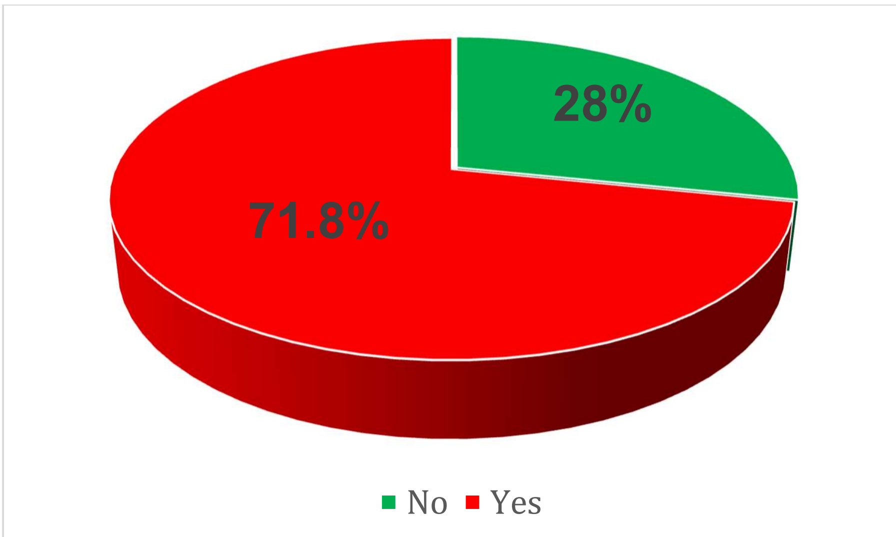


Figure 35: Prevalence of auditory exostosis

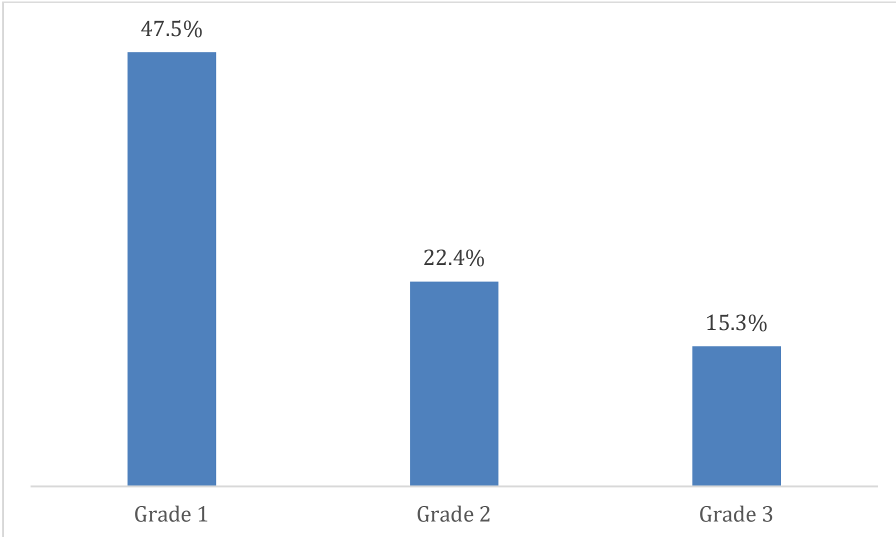


Figure 36: Severity of auditory exostoses

Discussion

The primary goal of the present research was to determine the prevalence of EAE in warm water surfers. To the best of our knowledge, this is the first study to assess the presence of EAE in surfers exclusively exposed to water temperatures above 19°C. The overall prevalence of the condition in our study was 71.8%. Considering that approximately 10% of the Australian population regularly surf,[46] this condition potentially affects nearly 45,000 individuals on the Gold Coast region of Australia.

This prevalence is comparable to what has been previously reported for cold water surfers, with results ranging from 61 to 80%.[58,64,169-173,178,180] Moreover, this prevalence is in line with a previous study conducted by Hurst et al.[64] in Victoria, Australia, where the authors reported a prevalence of 76%. Interestingly, a second study conducted in Australia, via an online survey, identified less than 4% of the surfers (3.5%) reported having EAE.[65] A likely explanation for the difference between self-reported and assessed prevalence is the potential lack of awareness of surfers about EAE. It is important to highlight that our study had the highest mean age (52.1 years ±12.6) and the greatest number of years of surfing experience (35.5 years ±14.7), when compared to previous studies. Nonetheless, our main finding highlights that EAE is highly prevalent in surfers, regardless of water temperature. Additionally, it further supports the concept that surfing exposure is potentially the most important predictor of EAE prevalence.

Nearly sixty percent of our volunteers had bilateral lesions, consistent with what has been reported previously in the literature. Some studies have suggested that the ear (right or left) more exposed to the prevailing wind would have a higher prevalence of EAE and more severe lesions.[64,169,181] The predominant coastal wind on the Gold Coast region is south-southeast (SSE);[296] however, there was no evidence of a statistical difference in prevalence and severity of EAE between the right and left ears of participants. With regards to severity, the majority of the volunteers in our study (47.5%) only had a mild grade EAE (grade 1), a result that is consistent with previously reported findings. Four individuals (6.6% of those with EAE) who had undergone EAE surgery, had a recurrence rate of 50%. Although surgery is the only treatment for the condition, recurrence is common, even in individuals who stop participation in ocean sports.[62,174]

The current study found that otological symptoms are common in the surfing population, as nearly two-thirds of the participants reported having regular symptoms; however, hearing loss, a common symptom associated with EAE, due to the obstructive characteristic of the condition, was significantly associated with age. Furthermore, we did not find a statistically significant association between symptoms and either the presence or severity of EAE. Also, these outcomes were not associated with the most commonly cited risk factors, namely surfing experience and winter exposure, or with the use of prevention methods. It is important to note that these findings must be interpreted with caution, mainly due to the study design, but also due to the relatively low number of participants in the study. A further limitation of the present study is the lack of investigation of costs associated with having the condition, and also number of days of work lost due to complications related to EAE.

Conclusion

The purpose of the current study was to assess the lifetime prevalence of EAE in warm water surfers. To the best of our knowledge, this is the first study assessing exostosis in surfers surfing exclusively in water temperatures above

19°C. Our findings revealed a prevalence of 71.8%, demonstrating that exostoses of the EAC are highly prevalent in warm water surfers, just as they are in cold water surfers. Furthermore, the results support the impression that surfing experience is potentially the most important predictor of prevalence. Health practitioners, especially General Practitioners and medical specialists, should be aware of this EAE prevalence in their surfing (and aquatic) patients and approach individuals susceptible to the condition, regardless of water temperature, in order to provide preventive recommendations for this population. Future research should focus on effective preventive methods for EAE.

Chapter 8: Lifetime Prevalence of Exostoses in New Zealand Surfers

Preface

Continuing on with the same line of research followed in the preceding chapter, regarding the bone health of the external auditory canal (EAC), this chapter explores the prevalence of external auditory exostosis (EAE) in cold water surfers.

As reported in Chapter 2, a discrepancy was found in prevalence of EAE when self-reported by surfers and compared to assessment via otoscopic examination. Therefore, the key aim of this chapter was to assess the prevalence of EAE via online survey in a notably cold water region (New Zealand), where prevalence of the condition has been previously reported at 73%, via otoscopic examination.[170]

This chapter was published in the Journal of Primary Health Care, and is formatted according to the journal's guidelines. Appendix X contains the published version of the manuscript.

***Simas V**, Remnant D, Furness J, Bacon C, Moran R, Hing W, Climstein M. Lifetime Prevalence of Exostoses in New Zealand Surfers. J Prim Health Care. 2019 Apr;11(1):47-53. doi: 10.1071/HC18097.*

Abstract

Introduction. External auditory exostosis (EAE) is a benign, irreversible bony outgrowth that arises from the temporal bone. EAE projects into the external ear canal, potentially causing recurrent otitis externa and conductive hearing loss.

Aim. Determine lifetime prevalence of EAE in New Zealand (NZ) surfers.

Methods: Online national survey.

Results: Included 1,376 NZ surfers (recreational=868, competitive=508). Mean surfing experience was 16.2 years, the majority self-classified as advanced (36.5%) followed by intermediate (30.2%), expert (20.1%) and beginner (13.2%). Surfers reported an average 214.2 hours surfing (28.6% during winter) the previous year. Overall lifetime prevalence of EAE was 28.9% (32.1% male, 14.6% female, $p<0.001$) with the highest proportion of EAE observed bilaterally (21.3%). Competitive surfers reported a significantly ($p<0.001$) higher lifetime prevalence of EAE than recreational surfers (45.3% versus 19.2%). We identified a significantly higher ($p<0.001$) lifetime prevalence of EAE as skill level increased (7.1% in beginners to 55.6% in experts) and two-fold increase ($p<0.001$) of EAE in top vs bottom quartile of surfing exposure. Neither winter surfing exposure nor which Island surfed were associated with EAE prevalence.

Discussion. Though not as high as a previous NZ study which utilized otologic exam, this study indicated almost one third of NZ surfers reported a previous diagnosis of EAE. General Practitioners are advised to conduct regular otologic assessment of patients who surf and advise appropriate prevention strategies. Large lesions and recurrent ear infections of progressive hearing loss should be referred to an Otorhinolaryngologist.

Keywords

Auditory exostoses; Surfing; Surfer's ear; Otology; Preventive medicine; Sports medicine

What gap this fills

What is already known: external auditory exostosis (EAE) is a reactive process that has been documented in surfers in Australia, Japan, Ireland, USA and the UK who were repeatedly exposed to water temperatures below 19^{o}C. New Zealand (NZ) water temperatures range from 9.5^{o}C to 21^{o}C depending upon latitude and season. Therefore, NZ surfers are likely to be susceptible to EAE.

What this study adds: This research identified a 29% lifetime prevalence of EAE in NZ recreational and competitive surfers. These findings highlight the importance of regular otologic screening by General Practitioners of patients who surf to identify EAE in the early stages and promote preventative care measures.

Introduction

External auditory exostosis (EAE), also known as Surfer's Ear, is an abnormal broad-based projection of the temporal bone into the external auditory canal (EAC).[293] Although benign and usually asymptomatic, it is an irreversible condition that can lead to potentially serious complications. Commonly found bilaterally, with multiple lesions, patients can present with chronic cerumen impaction, recurrent otitis externa, otalgia and conductive hearing impairment, due to stenosis of the EAC.[58] When assessed by otoscopy, the prevalence of EAE in surfing populations range from 38 to 80%.[58,169]

Surgical removal is the only treatment of auditory exostosis.[293] However, the procedure does not prevent recurrence, is technically challenging and may be associated with complications, such as hearing loss, tympanic membrane rupture, damage to the facial nerve, and stenosis of the EAC.[62,174] Therefore, surgery is reserved for selected cases, usually performed in patients with severe and symptomatic lesions. Prevention of EAE remains insufficiently investigated. However, regular use of protective equipment, such as earplugs, hood, or swim cap, is recommended, as it may assist in preventing the occurrence of auditory exostoses.[56,184]

The precise mechanism for the development of EAE is not fully understood. However, it is believed that cold conditions stimulate osteoblastic activity, leading to the development of exostoses.[178,183] Consequently, exposure to cold water and wind are recognized as risk factors, affecting prevalence and severity. Additionally, the incidence is highly correlated with the amount of time spent in the water, with risk increasing after five sessions of surfing per month, and significantly increasing after five years surfing.[54,179]

Sea water surface temperatures in New Zealand (NZ) range from 9.5 to 21 degrees Celsius (^{o}C) depending upon latitude and time of the year, with annual mean temperatures of approximately 15 to 17^{o}C north of the Wellington region, 13 to 14^{o}C in Wellington, Canterbury and Westland, and 12^{o}C in Otago and Southland.[300-302] This temperature range has been correlated with high prevalence of exostoses.[171,172,178] However, in NZ, only one study, published in 1998, has investigated the occurrence of EAE.[170] The research was conducted in 1994 by Chaplin et al.[170] who objectively assessed 92 amateur surfers and surf lifesavers via otoscope, in Dunedin (Otago region), and reported a prevalence of 73%.

Currently, it is estimated that nearly 315,000 people aged 15 and over surf in NZ,[305,306] a participation that doubled since the study by Chaplin et al.[170] was published.[307] The occurrence of EAE is a concern, and given the adverse effects of EAE and the limited data on its prevalence, further research on its prevalence in NZ surfers is warranted. Therefore, the aim of this study was to determine the lifetime prevalence of EAE in NZ surfers.

Methods

We conducted a national web-based, descriptive cross-sectional epidemiological study on NZ recreational and competitive surfers to determine the lifetime prevalence of EAE. An online questionnaire was created and distributed using a web-based application (SurveyMonkey, Palo Alto, CA, USA). The questionnaire was modified from a previous study of Australian surfers[47] and included two sections. Section 1 included questions about gender, age, years of surfing, participation type (recreational surfers were defined as those who had never participated in a competition and competitive surfers as those who had competed at local, national or international levels) and surfing exposure (ie, hours surfed per week during summer and winter). Additionally, surfing skill level was determined using a modified version of the Hutt Scale.[287] Section 2 included questions related to surfing injuries (traumatic and gradual-onset), as well as questions pertaining to history of unilateral or bilateral EAE, as diagnosed by their doctor.

Survey questions consisted of single choice, multiple choice, dropdown list, numerical input and short answer free text. Filters and this array of questions were used to abbreviate response times and minimize incomplete responses.

The study was promoted via newspaper articles, surf report websites, social media (free and paid advertisements) and through board-rider clubs and community notice boards. Participants in the study defined themselves as surfers currently in NZ. Only respondents who had more than 12 months surfing experience were included in analysis.

Ethics

This study was approved by the Unitec Research Ethics committee in accordance with the ethical standard of the Helsinki Declaration (UREC 2015-1032).

Statistical analyses

Data presented in Tables 22 and 23 are expressed as mean ± standard deviation (± S.D.), number (n) or percent (%). Normality of all data was assessed by investigating kurtosis, skewness, Q-Q plots, as well as the Kolmogorov-Smirnov test with the Lilliefors significance correction. Heteroscedasticity was also assessed using Levene's test for the equality of variances. Statistical significance between genders was determined using an independent samples t-test with alpha set (*a priori*) $p < 0.05$. A Pearson's correlation was utilized (where appropriate) to determine relationships. Chi-square test of homogeneity and binomial logistic regression were also conducted. All analyses of the data was completed using SPSS (Ver 24.0, IBM Corp., Armonk, NY).

Results

A total of 1,473 participants completed the questionnaire, of whom 1,376 (89.2%) completed the exostoses questions and are reported in this study. Most respondents (~95%) completed the questionnaire online, versus face-to-face with one of the researchers at popular surf breaks. The majority of participants currently resided in NZ (for at least 6 of the previous 12 months). Of all participants, the majority predominantly surfed in the North Island (86%), with almost a third surfing mostly in the Auckland region (31%). The most identified ethnic group(s) were NZ European (85% of participants) and Māori (12%). The Māori proportion of surfers being only slightly less than the Māori proportion (15%) reported in the 2013 NZ Census.[309]

Participant ages ranged from 8 to 74 years (y) (males 8 y to 74 y (n=1,123); females 13 y to 62 y (n=253), Figure 37).

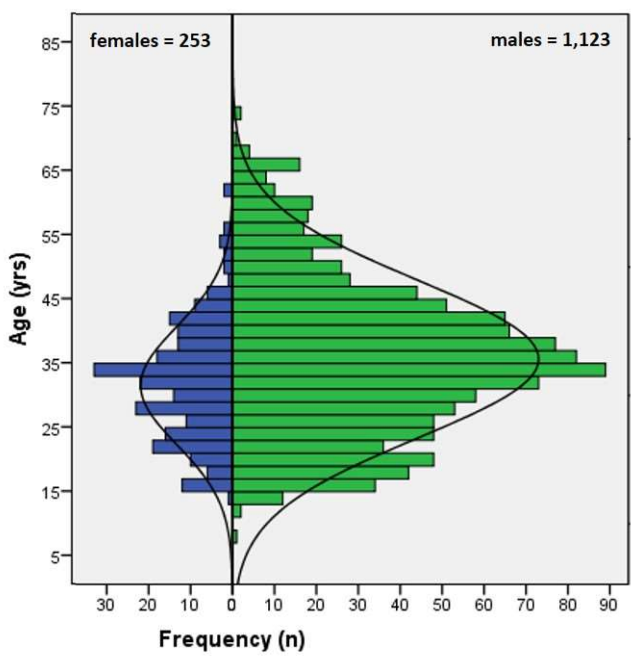


Figure 37: Population pyramid of participants (line of normality indicated)

Median surfing experience was 13 y (interquartile range 8 y to 28 y) with the majority classified as advanced or expert (57.1%). Surfers spent a median

130 h surfing (interquartile range 55 h to 276 h), 28% during winter, the previous 12 months. Table 22 shows participant characteristics by gender.

Table 22: Demographics of participants

Variable	Total (n=1,376)	Males (n=1,123)	Females (n=253)
Age (y)	34.9 ± 11.8	35.7 ± 12.3	31.5 ± 9.2 **
Mass (kgs)	78.0 ± 14.0	81.5 ± 12.5	62.7 ± 8.9 **
BMI (kg/m^2)	24.8 ± 4.3	25.2 ± 4.1	22.8 ± 4.3 **
Surfing experience (y)	16.2 ± 11.2	17.8 ± 11.2	9.3 ± 8.3 **
Surfing location			
• North Island	85.8	85.3	88.1
• South Island	13.2	13.7	10.7
Surfing status (n)			**
• Recreational	63.1	60.9	72.7
• Competitive	36.9	39.1	27.3
Surfing level			**
• beginner	13.4	7.5	39.5
• intermediate	29.5	26.5	42.7
• advanced	37.0	42.2	13.8
• expert	20.1	23.8	4.0
Total surfing (h/y)	214 ± 250	226 ± 254	163 ± 228 **
Percent surfing winter (%/y)	28.6 ± 18.7	29.8 ± 18.1	23.2 ± 20.2 **

Values are mean ± SD or percentage. * $p<0.05$; ** $p<0.001$ for between-gender difference.

The group lifetime prevalence of EAE in the surfers (recreational and competitive) was 28.9% with males having a significantly higher ($p<0.001$) relative lifetime prevalence compared to females (Table 23). The youngest surfer to report having EAE was a 13-year-old female, who started surfing at the age of 5 y. The highest percentage of EAE reported was bilaterally (73.8% of EAE cases, *p*<0.001), with no statistical difference between left and right ears (Table 23).

Table 23: Lifetime prevalence of exostoses

Variable	Total (n=1,376)	Males (n=1,123)	Females (n=253)
Exostoses	397 (28.9)	360 (32.1)	37 (14.6) **
Bilateral exostoses	293 (21.3)	270 (24.0)	23 (9.1)
Unilateral exostoses	104 (7.6)	90 (8.0)	14 (5.5)
• Left ear	47 (3.4)	42 (3.7)	5 (2.0)
• Right ear	57 (4.1)	48 (4.3)	9 (3.6)

Values are n (percentage). ** *p*<0.001 for between-gender difference (exostoses only).

Competitive surfers reported a significantly higher relative lifetime prevalence of EAE compared to recreational surfers (45.3% versus 19.2%, *p*=0.001). We identified a significantly higher lifetime prevalence of EAE as skill level increased (7.1% in beginners, 14.5% in intermediate, 33.6% in advanced and 55.6% in experts; *p*<0.001). When we evaluated the top and bottom quartiles of surfing exposure (≥276 h/y_versus ≤55.15 h/y) we found a two-fold higher lifetime prevalence of EAE in the highest quartile compared to the lowest quartile (119 surfers, 34.5%, versus 60 surfers, 17.4%; *p*<0.001). Because cold water exposure might influence EAE, we also compared the lifetime prevalence of EAE between the top and bottom quartile of winter surfing exposure (h/y) and between predominant island of surfing (North versus South). Slight differences in EAE prevalence between highest and lowest quartile of winter surfing exposure (34.2% versus 25.0%, *p*=0.2) and North and South Island (28.5% versus 30.9%, *p*=0.7) did not attain statistical significance.

Seventy-seven percent of the surfers reported surfing for more than 5 y, and this group had a significantly higher (p<0.001) prevalence of EAE (35.3%) than those surfing less than 5 y. Binomial logistic regression was performed to ascertain the effects of surfing for more than five years on the likelihood that participants have Surfer's Ear. The logistic regression model was statistically significant, $\chi 2 = 119.051$, p<0.001, and correctly classified 71.3% of cases. Participants who surfed for more than 5 y had 7.4 times higher odds of reporting exostosis compared to those who had not surfed for this length of time. Table 23 illustrates our findings with regard to exostoses reported by participants.

Discussion

The aim of this study was to identify the lifetime prevalence of EAE in NZ surfers. We surveyed 1,376 surfers and, to the best of our knowledge, it is the largest cohort to date to be screened for EAE in NZ and the most representative of the NZ surfing population. Our findings revealed a prevalence of 28.9%, with nearly three-quarters of those reporting the condition bilaterally. This suggests that EAE has the potential to affect nearly 100,000 surfers in the country. This number is likely to rise, due to the increasing popularity of surfing in NZ, which is mainly attributed to the country's coastline, allowing easy access to a range of good quality surf breaks.[310]

Described since the 1800s,[311] EAE has been associated with water sports from early stages of its investigation.[165] In an anthropological study,[180] the condition was found to be more prevalent in populations who depended on aquatic resources and lived between the latitudes of 30° and 45° North and South, where the annual mean water temperature is below 19°C. New Zealand is geographically located below the latitude of 30° south, with most of the country's coastline situated between 35° and 45°.[313] The highest annual-mean surface water temperatures are around 17°C, measured in sites in Auckland and Northland, in the North Island.[301] Therefore, NZ surfers are exposed to conditions conducive for the development of EAE.

The first study to determine the prevalence of EAE in NZ was conducted in 1994 by Chaplin et al.,[170] who reported a prevalence of 73%. Today, this would represent nearly 230,000 surfers being exposed to the condition, a number more than two times higher than what was found in the present study. Chaplin et al. reported that 92% of people surfing for more than 10 y had developed exostoses. The mean surfing experience of our cohort was 16.2 y; consequently, we expected to find a higher prevalence then what was actually observed. The discrepancy between the results could be partially explained by the fact that the majority of the surfers in our study (86%) were from the North Island, with almost one third from the Auckland region (mean water temperature of around 17°C,[301] whereas 92% of the participants investigated by Chaplin et al.[170] were from the South Island, with many probably local to the Otago area (mean water temperature of approximately 12°C).[301] A strong relationship between cold-water exposure and EAE has been reported in the literature.[62,63,180,314] However, the findings of the present investigation have been unable to demonstrate this correlation, as there was a non-significant difference between top and bottom quartiles for winter hours surfing exposure and exostoses. Chaplin et al.[170] noted that the seven surfers from the North Island had less severe exostoses than those from the South Island, despite a similar exposure of surfing in winter (p<0.005); however, they did not report difference in prevalence between islands. Similarly, in the present study, we find no difference in lifetime EAE prevalence between surfers predominantly surfing in the North versus South Islands and no difference in prevalence according to time spent surfing in winter months.

Another explanation for the difference in EAE prevalence noted here and previously could be related to the methods used to assess EAE. Chaplin et al.[170] examined participants via operating microscope by two assessors, who assessed the presence and severity of EAE. In our study, surfers answered a questionnaire where they were asked whether they had previously had EAE, as diagnosed by a doctor. An even larger disparity in the prevalence of EAE was noted in two Australian studies.[64,65] Results from a study assessing self-reported surfing injuries, but not specifically questioning about EAE, noted that only 3.5% reported having a surfing related ear injury.[65] This is in contrast to the results of Hurst et al.[64] who assessed the condition via otoscopy and reported a prevalence of 76%. The incongruity between self-reported and assessed prevalence may suggest low awareness of surfers about the condition, which yields concerns with respect to the condition being overlooked by health practitioners.

Previous studies have established that exostoses are highly correlated with the amount of time spent in the water, with risk increasing after five sessions of surfing per month, and significantly increasing after five years surfing.[54,179] The current study found that surfers in the top quartile of surfing exposure (h/y) had a two-fold increase in the prevalence of EAE. Consistent with the literature, we found that participants who reported surfing for more than 5 y reported higher prevalence of EAE than those who had surfed for less than 5 y, having more than seven times higher odds of developing the condition. One interesting finding is the age of the youngest surfer to report having EAE. This participant was a 13-year-old female, with 8 years of surfing experience. Traditionally, it has been shown that EAE is more commonly found bilaterally,[293] which is in accordance with the present results, where we found that nearly 74% of the surfers with EAE had both ears affected by the condition, with no difference between left and right ears. This finding is also consistent with that of Chaplin et al.,[170] who reported that statistically both ears were affected in the same proportion.

One of the strengths of this study is the large sample size included in the final analyses, which allows for more precise estimates. Furthermore, we conducted a national survey, aiming to reach a representative spread of individuals throughout the country, which included recreational and competitive surfers. However, several limitations should be acknowledged. Firstly, the prevalence of EAE was based on self-reported information and not on otologic examination, and therefore the prevalence reported here may be underestimated. Additionally, this design did not allow us to gather data on the severity of the condition. Secondly, almost all of the participants were currently residing in NZ having lived in the country for 6 months of the previous 12. This population might, therefore, have included surfers who had previously lived in places where surf conditions, such as warm water, may be associated with a lower prevalence of exostoses. Past movement between regions may also explain lack of difference between those who currently predominantly surf in the North versus South Islands. Thirdly, we did not include questions related to the use of protective equipment. Protective equipment is recommended by the American Academy of Family Physicians[184]; however, Chaplin et al.[170] reported that no differences in prevalence were noted between surfers who wore protective earplugs and those who did not. Lastly, we did not account for participation in other water activities; notwithstanding, the study by Chaplin et al.[170] reported no significant difference between individuals who engaged in other water sports and those who did not.

Conclusion

The results of this investigation have shown that the prevalence of EAE, although lower than a previous study assessing NZ surfers in the southern region of the country, is likely to affect nearly 100,000 individuals in NZ. Moreover, we were able to demonstrate that individuals surfing for more than five years are exposed to an increased risk of developing exostoses, and the lesions can start developing at an early age, as early as 13 y. There is, therefore, a need for screening in the general practice setting of individuals who surf, focusing on raising awareness and aiming at prevention of this condition. In addition to this, where EAE is present General Practitioners should refer severe cases, or individuals with clinically important symptoms, such as recurrent ear infections or progressive hearing loss, to a specialist. Further work should focus on assessing surfers via otologic examination, determining not only the prevalence but also severity of the condition, correlating the findings with symptomatology.

Chapter 9: Australian surfers' awareness of 'surfer's ear'

Preface

This chapter continues on the same line of research as that followed in the preceding chapter, regarding the bone health of the external auditory canal (EAC), and is the last in the second major focus area of this thesis.

The key aim of the present chapter was to explore awareness of external auditory exostosis (EAE) and associated prevention strategies amongst Australian surfers, a specific objective of this program of research. The foundation of this chapter was the discrepancy between self-reported prevalence of EAE and the prevalence found when assessed via otoscopic examination, a disparity illustrated by Chapters 7 (prevalence assessed via otoscopy, 71.8%) and 8 (self-reported prevalence, 28.9%).

This chapter was accepted for publication in the BMJ Open Sport & Exercise Medicine, and is currently under review.

***Simas V**, Hing W, Pope R, Climstein M. Australian surfers' awareness of 'surfer's ear'. (Accepted, BMJ Open Sport & Exercise Medicine).*

Abstract

Purpose

This study aimed to assess awareness of external auditory exostosis (EAE) amongst Australian surfers.

Patients and methods

This research used a cross-sectional observational design, assessing professional and recreational Australian surfers. Currently active surfers over 18 years of age, surfing year-round, were eligible to participate. Individuals who successfully passed an initial screening were asked to complete a questionnaire detailing basic demographic data, surfing habits, otological history, awareness of EAE, and use of protective equipment for the condition. After completing the questionnaire, all volunteers underwent bilateral otoscopic examination, in order to assess the presence and severity of EAE.

Results

A total of 113 surfers were included in the study and were divided into two groups, based upon surfing status: 93 recreational surfers and 20 professional surfers. Recreational surfers were significantly older ($p<0.005$), more experienced (greater years surfing; $p<0.005$), with lower prevalence of otological symptoms ($p<0.05$). The most common symptoms were water trapping, impacted wax, and hearing loss. Prevalence of EAE was high for both groups (95% in the professional surfers and 82.8% in the recreational surfers); however, recreational surfers had mild grade EAE (Grade 1) as the most common presentation, as opposed to professionals who had a severe grade EAE (Grade 3) as the most common presentation ($p<0.05$ between groups). Awareness of the term ‘surfer’s ear’ was high for both groups, as was knowledge of prevention options. However, fewer considered the condition to be preventable, and an even lower number reported regular use of prevention methods.

Conclusion

Australian surfers had a high level of awareness of EAE; however, few reported utilizing prevention methods, despite having a high prevalence of the

condition. Health practitioners should screen susceptible individuals in order to recommend appropriate preventive measures.

Keywords

Auditory exostoses; Surfing; Surfer's ear; Otology; Preventive medicine; Sports medicine

Introduction

External auditory exostosis (EAE), most commonly referred to as 'surfer's ear', is a well-known clinical complication associated with long-term surfing.[52,293] The irreversible bony growths in the external auditory canal (EAC) are benign, typically multiple, and found bilaterally. A diversity of clinical presentations has been reported, including an intermittent blocked feeling of the EAC, especially after water exposure, recurrent cerumen blockage, frequent ear infections, pain in the EAC, and hearing deterioration due to the obstructive nature of the condition.[293]

The condition is diagnosed via otoscopy to identify the broad-based bone outgrowths arising from the temporal bone. The pathophysiology of EAE is not fully understood, and prevention remains unclear, as only observational studies have investigated this topic. However, use of protective equipment (eg, earplugs and hoods) has been proposed to prevent its occurrence and is recommended.[179,184] Surgical removal is the only treatment for EAE, a procedure reserved for patients with severe and symptomatic cases; however, the treatment does not prevent recurrence,[62,174] highlighting the importance of prevention.

The prevalence of EAE in surfers ranges from 38 to 80%,[58,169] when assessed via otoscopic examination. The surfing population in Australia is estimated at approximately 2.5 million;[46] therefore, the condition potentially affects more than 900,000 individuals Australia wide, and the number of susceptible surfers can be as high as 2 million. However, there appears to be only two studies that have reported the prevalence of EAE in Australian surfers,[64,65] and a large discrepancy exists between the reported results. The first study was conducted by Hurst et al.,[64] where the authors assessed surfers via otoscopy and found a prevalence of 78%. In the second study, Furness et al.[65] conducted an online survey to investigate self-reported prevalence of chronic injuries related to surfing, and only 3.5% of the participants reported having EAE. The disparity in the results between both studies may be likely, in part, due to a lack of awareness of the condition by surfers.

Therefore, the aim of the present study was to assess awareness of 'surfer's ear' in a cohort of professional and recreational Australian surfers, including use of protective methods for EAE.

Methods

Study design

This research used a cross-sectional observational design. The study was approved by the Bond University Human Research Ethics Committee (BUHREC 15221).

Participants

Surfers were recruited from Australian boardrider clubs, professional surfing organizations (Surfing Queensland and the World Surf League), and through advertising in newspapers, surfing magazines, surfing websites and surf shops.

Eligibility criteria

Currently active Australian surfers, both professional and recreational, over 18 years of age, surfing all year round, and with a minimum of 5 consecutive years of surfing experience, surfing at least five sessions per month, were invited to take part in the research. Participants were excluded if both the right and left EAC were occluded by cerumen, as this prohibited otoscopic examination.

Procedures

The research took place at the Water Based Research Unit (WBRU), Bond Institute of Health and Sport, Bond University, Gold Coast (Queensland, Australia). An explanatory statement and informed consent form were given to all potential participants upon arrival at the WBRU. Prior to providing written informed consent, all potential participants were given the opportunity to ask any questions about the research and about the testing procedure. Each of them received a handout illustrating the otoscopic exam to be conducted, which also contained a simple overview of the research project and its purpose. The informed consent form was signed by those who were satisfied with the information provided and volunteered to participate.

At the WBRU, participants were asked to complete a questionnaire to collect basic demographic data and to examine their surfing habits, otological history, knowledge about EAE, and utilization of protective equipment. After completing the questionnaire, all participants underwent clinical examination of both ears, via otoscopy, by an experienced Sport and Exercise Physician, using a hand-held, battery-powered digital otoscope (Digital MacroView™, Welch Allyn®, USA), capable of acquiring digital images.

Outcome measures

In the questionnaire, participants were assessed with regard to surfing experience in years, and stance while surfing (ie, 'regular' if left foot forward or 'goofy' if right foot forward). They were then asked whether they had heard of surfer's ear, whether they considered it to be a preventable condition, whether they knew of any forms of prevention, and about their regular use of protective equipment (eg, ear plugs, hood). They were also asked about otological symptoms (eg, otalgia, hearing loss), and whether they had previously seen a doctor (general practitioner or specialist) because of otological complaints. Additionally, they were questioned about previous history of otitis externa (OE) and EAE.

All participants had their ear examined via otoscopy, and digital images of the EAC were recorded. Images were assessed to determine the presence of EAE and, if any lesions were present, the degree of severity, based on the obstruction of the EAC. The grades of severity were based on a previously published one-to-three scale[173] (Figure 38; grade 1: up to 33% of obstruction; grade 2: between 34% and 66% of obstruction; grade 3: more than 67% of obstruction).

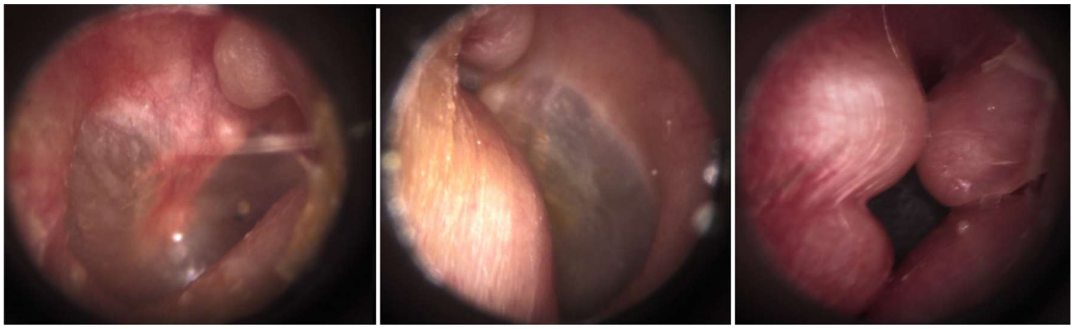


Figure 38: Exostosis grades of severity

Notes: Grade 1: up to 33% of obstruction of the external auditory canal (EAC); Grade 2: between 34% and 66% of obstruction of the EAC; Grade 3: more than 67% of obstruction of the EAC.

Data analysis

Data were analyzed descriptively to determine means and standard deviations (SD) and tested for normality by assessing skewness, kurtosis, Q-Q plots, and the Kolmogorov-Smirnov test. For continuous variables, differences between professional and recreational surfers were assessed using independent-samples *t*-tests, or, for non-normally distributed variables, Mann-Whitney-U tests. For categorical outcomes, a Chi-square test of independence was used to assess any differences between the groups. The level of significance, alpha, was set *a priori* at 0.05 for all statistical tests. All analyses were performed with SPSS statistical software (Version 25.0 for Windows, SPSS Inc., Chicago IL, 2017).

Results

A total of 113 surfers (90.3% males) were eligible to take part in our study; 93 recreational (82.3%) and 20 professionals (17.7%). Table 24 shows characteristics for both professional and recreational groups. Recreational surfers were significantly older ($p<0.005$), more experienced (greater years surfed; $p<0.005$), and had a lower prevalence of regular otological symptoms ($p=0.017$) than professional surfers. Of those participants reporting otological symptoms (18 professional surfers; 63 recreational surfers), the most common complaints were water trapping (88.9% of professional surfers, 66.7% of recreational surfers), impacted wax (83.3% of professional surfers, 61.9% of recreational surfers), and hearing loss (44.4% of professional surfers, 49.2% of recreational surfers). Of note, the number of surfers who had previously sought medical advice due to otological symptoms was high for both groups (60% of professional surfers and 62.4% of recreational surfers).

Table 24: Participants' characteristics

Characteristics	Professional group (*n*=20)	Recreational group (*n*=93)
Age in years (Mean ± SD) (*)	29.0 ± 4.0	52.3 ± 12.9
Gender (*n* (%))		
- Male	14 (70%)	88 (94.6%)
- Female	6 (30%)	5 (5.4%)
Surfing experience in years (Mean ± SD) (*)	21.2 ± 5.6	36.0 ± 15.0
Stance (*n* (%))		
- Regular	16 (80%)	70 (80.6%)
- 'Goofy'	4 (20%)	18 (19.4%)
Regular otological symptoms (*n* (%)) (*)	18 (90%)	63 (67.7%)
Average number of regular symptoms (Mean ± SD)	2.9 ± 1.1	2.3 ± 1.3
Previously seen Doctor due to otological symptoms (*n* (%))	12 (60%)	58 (62.4%)
Previous otitis externa (*n* (%))	12 (60%)	38 (41.2%)
Previous diagnosis of EAE (*n* (%))	4 (20%)	24 (25.8%)
Previous surgery for EAE (*n* (%))	2 (10%)	4 (4.3%)

Note: (*) denotes statistically significant difference between groups (p<0.05). **Abbreviations:** *n*, number of individuals; SD, standard deviation; EAE, external auditory exostosis;

Auditory exostosis was diagnosed in 19 professional surfers (95%) and 77 recreational surfers (82.8%), with no statistical difference between groups (Figure 39). However, as can be seen in Figure 39, Grade 3 EAE was significantly more prevalent in the professional group (p<0.05), whereas Grade 1 EAE was significantly more prevalent in the recreational group (p<0.05). Of those having EAE, the majority of the individuals had bilateral lesions; however, a significantly higher number of surfers in the professional group were found to have bilateral lesions (94.7% in the professional group versus 58.4% in the recreational group; p<0.05). Notably, only 20% of professional surfers and 25.8% of recreational surfers had been previously diagnosed with EAE (Table 24). The recurrence rate following surgery, where this had occurred, was high for both groups: 100% in the professional group (2 out of 2) and 50% in the recreational group (2 out of 4).

With regards to awareness, most participants in both groups (100% of the professional surfers and 88.2% of the recreational surfers) had previously heard of the term 'surfer's ear' (Figure 40), with no significant difference between the groups in this regard. However, fewer individuals considered the condition to be preventable, despite the fact that most participants could cite at least one prevention method (no significant difference between groups). Interestingly, in both professional and recreational groups, even though there was a high level of awareness of the condition amongst participants, very few surfers reported using prevention methods on a regular basis – a number that was even lower in the professional group. The only professional surfer who reported regular use of earplugs started using the protective equipment after being diagnosed with EAE. In the recreational group, only 8 out of the 24 previously diagnosed with EAE (33.3%) reported regular use of protective equipment. The most commonly cited form of prevention was earplugs, with all (100%) professional surfers that were aware of prevention options citing this as the only effective method. Within the recreational group, of those aware of prevention methods (67 surfers), 73.1% cited earplugs, 11.9% cited alcohol-based eardrops, 7.5% cited hoods, and 7.5% cited a combination of the previous three methods. For both groups, the most common reason for not using prevention methods was that it can potentially affect performance, by affecting both hearing and balance.

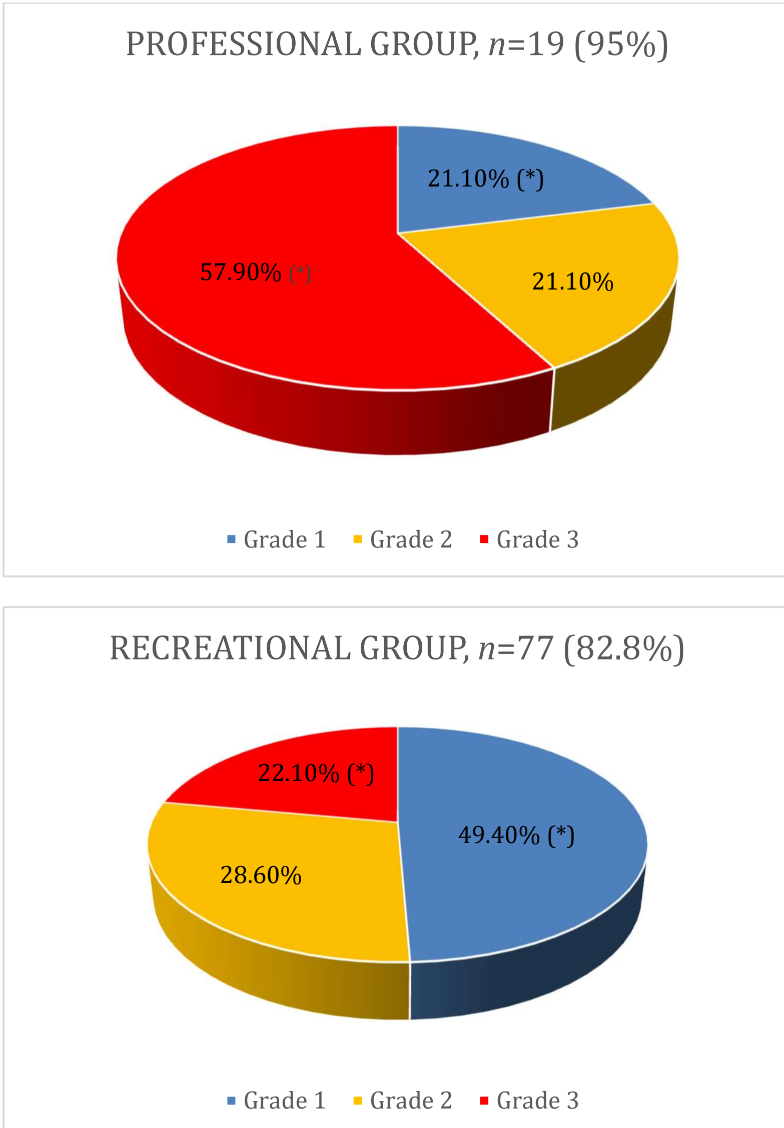


Figure 39: Prevalence and severity of auditory exostosis

Note: (*) denotes statistically significant difference between groups (p<0.05). **Abbreviation:** n, number of individuals with auditory exostosis.

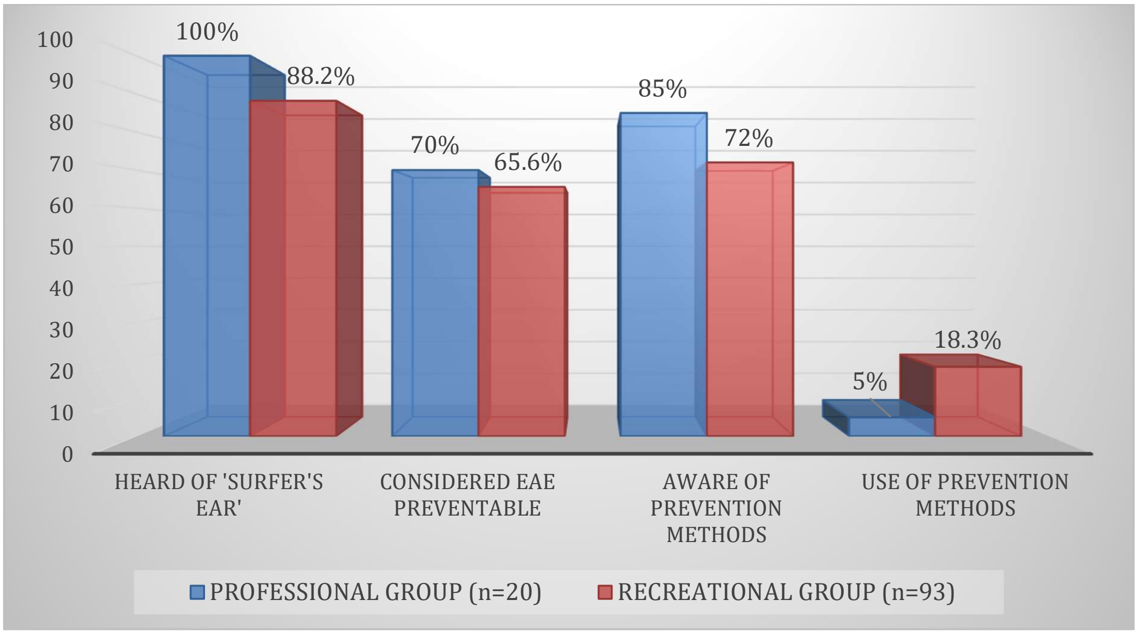


Figure 40: Awareness and use of prevention methods

Abbreviation: EAE, external auditory exostosis.

Discussion

The primary goal of the present research was to determine level of awareness of EAE amongst professional and recreational Australian surfers. Additionally, we aimed to assess the use of protective equipment by the participants.

Our results revealed a high prevalence of EAE in both recreational and professional surfers (82.8% and 95%, respectively; Figure 39). However, only 25.8% of the participants in the recreational group and 20% of the professional group had been previously diagnosed with EAE. Interestingly, most of the individuals in both groups had previously reported otological symptoms and had seen a health practitioner for that complaint (Table 24).

The term 'surfer's ear' is well-known amongst surfers (Figure 40) and most of the participants cited at least one form of potential prevention for the condition. However, fewer considered the condition to be preventable, and this may be one of the explanations for the low number of surfers who reported regularly using prevention methods. Nonetheless, as earplugs were the most common cited prevention form, it may also be associated with the affected performance caused by the equipment, as many surfers reported this as the main reason for not using this protective equipment. In a study conducted in the United Kingdom investigating awareness and attitudes of surfers towards EAE,[316] it was reported that the majority of the participants (66.6%) believed that the condition was inevitable. Additionally, many surfers in the study similarly reported that earplugs reduced balance and limited their surfing performance.

Earplugs appear to be the most common prevention method reported in the literature[62,179]; however, their value remains unclear, as there appear to be no trials assessing the long-term benefit and efficacy, including usage rate, amongst surfers. Alternative options should also be investigated, such as hoods and different formulations of ear drops. Furthermore, future research should assess barriers to the use of protective equipment by surfers, in order to inform recommendations for prevention methods.

Conclusion

The purpose of this study was to assess awareness of EAE amongst Australian professional and recreational surfers, and also the use of prevention methods in this population. Despite a high level of awareness, the use of prevention methods was low. Health practitioners are encouraged to discuss EAE with their patients who regularly surf, as otological symptoms are common and surfers seek medical advice for this reason. Prevalence of EAE and its recurrence after surgical procedure are high; therefore, future research should focus on effective prevention methods for this condition.

Chapter 10: Discussion

Summary of key findings

This thesis investigated two main focus areas relating to bone health and surfing, these being skeletal bone health and the bone health of the external auditory canal (EAC). The key findings are discussed separately, in the sections that follow, according to these two focus areas of the thesis.

Skeletal bone health

Our systematic review (Chapter 3) found that water-based exercise, although not as effective as land-based exercise, is an alternative form of physical activity with potential to decrease the rate of bone loss in post-menopausal women. Further, the meta-analyses suggested that potential increases in bone mineral density and positive effects on bone metabolism and muscle strength were associated with water-based exercise, in this population. Unfortunately, the results cannot be extrapolated to the men, as no study included in the review assessed a male population. The clinical relevance of these findings is apparent: those who may prefer or be best suited to water-based exercise, or enjoy it alongside land-based exercise, are likely to achieve benefits in bone health. Thus, water-based exercise should be encouraged, alongside land-based exercise, to help prevent age-related bone deterioration and conditions such as osteopenia and osteoporosis.

In Chapter 4, the most appropriate positioning protocols when conducting DXA scans were determined, and we were able to demonstrate high intra-rater reliability for the assessment of body composition and bone mineral density (BMD) at the lumbar spine and the hip (femoral neck and total hip). Specifically, and of clinical relevance, we found that the systematic use of positioning protocols increases the reliability of results, and that the Nana positioning protocol, for body composition scans, and the ANZBMS positioning protocol, for BMD scans, both have excellent reliability and produce low error rate (SEM% and SRD%).

In line with the findings of our systematic review (Chapter 3), the cross-sectional study reported in Chapter 5 demonstrated that the physical demands associated with surfing are potentially enough to stimulate the bone tissue of middle-aged and older men, a result illustrated by the positive outcomes observed in the surfing population when compared to an age- and sex-matched physically active population of non-surfers engaged in non-weight-bearing/low impact activities. This, again, has clear clinical relevance, since it indicates that older men who surf gain a benefit for bone health from that surfing activity, and so should be encouraged to remain active in their surfing pursuits.

Bone health of the external auditory canal

With regards to the EAC, the case study provided in Chapter 6 identified that external auditory exostosis (EAE) is a common condition in surfers; however, typically undiagnosed at a mild grade.[293] As a silent disorder, it predisposes surfers to potentially serious health issues, when it progresses to more severe grades.[293]

It was evident from our findings in Chapter 7 that this condition is important, regardless of the water temperatures in which surfers enjoy their sport, as demonstrated by the high prevalence of EAE, similar to that in cold water surfers, in surfers exposed to water temperatures above the traditional cut-off point of 19^{o}C. Furthermore, the results suggest that the number of years individuals are exposed to surfing is potentially the most important predictor of EAE. These findings are clinically relevant in revealing that any surfer surfing for more than five years should be assessed in relation to the bone health of the EAC. The findings also highlight the need for attention to be paid to prevention of this prevalent condition in surfers.

The cross-sectional study reported in Chapter 8 indicated that there is an important difference in prevalence rates when EAE is self-reported as opposed to when it is assessed via otoscopic examination. In the study conducted in New Zealand (Chapter 8), a notably cold-water region, where a previous study involving otoscopic assessment of participants reported an EAE prevalence of 73%,[170] we were able to identify a prevalence of only 28.9% via an online survey.

The result is in line with what we subsequently found in Chapter 9, where less than 30% of the participants reported being aware of having EAE, however, upon otological assessment, the true prevalence was revealed to be over 80%.

Interestingly, despite surfers knowing about EAE, only a small fraction of surfers regularly uses prevention methods (Chapter 9). These findings highlight the importance of the role of health practitioners in advising susceptible individuals, but also the need for greater focus on prevention of this highly prevalent condition.

Strengths and Limitations

This program of research is the first to address the role of water-based exercise on bone health of middle-aged and older women, through a methodologically rigorous systematic review, where we were able to include a meta-analytical approach. Additionally, the strict eligibility criteria applied to our studies helped to provide evidence with regards to the important gaps identified through our literature review.

Nevertheless, limitations should be acknowledged. The findings of the systematic review and meta-analysis (Chapter 3) were limited by the generally low quality of studies identified for inclusion in the review, suggesting that more studies are needed to address this topic of the impacts on skeletal bone health of water-based exercise modalities.

Due to budget limitations, the numbers of participants included in the biochemical analyses conducted in the study reported in Chapter 5 did not allow adequate statistical power to rule out a clinically significant association between surfing and bone turnover in older male surfers, or to assess the value of vitamin D as a supplement in that population.

Chapters 5, 7 and 9 used a cross-sectional study design, which limits the ability to identify cause and effect. Moreover, the numbers of participants recruited for those studies mean that caution should be applied in extrapolation of the findings to the general population.

In addition, despite the high number of participants analyzed in the New Zealand EAE paper (Chapter 8), the survey format, without accompanying physical examination, did not allow assessment of the severity of EAE.

Future research

Based on the findings of the current program of research, several recommendations can be made for future research.

Future research for skeletal bone health should use longitudinal designs with a long-term follow-up, in order to assess the effects of surfing, and other water-based exercise, on the skeletal bone health of middle-aged and older adults.

The high prevalence of EAE found in our research supports the need for future research to develop and explore the role and effectiveness of proposed protective methods, such as ear plugs, different formulations of ear drops, and hoods, in preventing EAE. Additionally, longitudinal studies in this area would help to understand the rate of growth between the grades of severity.

Conclusion

This program of research aimed to investigate the relationships between surfing and bone health. The specific objectives were achieved, as we were able to demonstrate that regular surfing can potentially decrease age-related bone deterioration. Additionally, our findings revealed that a negative bone-related effect, auditory exostosis, is highly prevalent in the surfing population, regardless environment where the sport is practiced, and prevention should be further investigated.

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Appendices

Appendix I: Effects of water-based exercise on bone health of middle-aged and older adults: a systematic review and meta-analysis – published version

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REVIEW

Effects of water-based exercise on bone health of middle-aged and older adults: a systematic review and meta-analysis

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Background: Age-related bone loss is a major health concern. Only exercises associated with high-impact and mechanical loading have been linked to a positive effect on bone turnover; however, these types of exercises may not always be appropriate for middle-aged and older adults due to physical decline or chronic disorders such as osteoarthritis. Water-based exercise (WBE) has been shown to affect different components of physical fitness, has lower risks of traumatic fracture, and applies less stress to joints. However, the effects of WBE on bone health are unclear.
Objective: This study aimed to explore whether WBE is effective in preventing age-related bone deterioration in middle-aged and older adults.
Methods: A search of relevant databases and the references of identified studies was performed. Critical narrative synthesis and meta-analyses were conducted.
Results: Eleven studies, involving 629 participants, met all inclusion criteria. All participants were postmenopausal women. Eight studies compared WBE to a sedentary control group, and four studies had land-based exercise (LBE) participants as a comparison group. Meta-analyses revealed significant differences between WBE and control group in favor of WBE for changes in bone mineral density (BMD) at the lumbar spine (mean difference [MD] 0.03 g/cm^2; 95% confidence interval [CI]: 0.01 to 0.05) and femoral neck (MD 0.04 g/cm^2; 95% CI: 0.02 to 0.07). Significant differences were also revealed between WBE and LBE in favor of LBE for changes in lumbar spine BMD (MD –0.04 g/cm^2; 95% CI: –0.06 to –0.02). However, there was no significant difference between WBE and LBE for changes in femoral neck BMD (MD –0.03 g/cm^2; 95% CI: –0.08 to 0.01).
Conclusion: WBE may have benefits with respect to maintaining or improving bone health in postmenopausal women but less benefit when compared to LBE. Further research is required on this topic.
Keywords: aquatic exercise, bone mineral density, osteoporosis, preventive medicine, sports medicine

Introduction

Age-related bone loss is a major health concern. Loss of bone mass and microarchitectural deterioration of bone tissue are directly related to a decrease in bone strength and subsequently increased fracture risk, which ultimately leads to conditions clinically known as osteopenia and osteoporosis.[1,2] Osteoporotic fractures have particular importance in public health and are considered one of the most common causes of disability, as well as a major contributor to medical care costs worldwide.[3] They are responsible for excess mortality, morbidity, chronic pain, reduction in quality of life, and admission to long-term care, significantly contributing to health and social care costs.[4] In Australia, it is estimated that osteopenia and osteoporosis affect ~7.5 million

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people, with one fragility fracture occurring every 3.6 minutes, which amounts to ~400 per day.[5–7] The estimated total number of osteoporotic new fractures and refractures over the period 2012–2022 is predicted to be in excess of 1.6 million, with an estimated total direct and indirect cost to the Australian government, community, and individuals of AU$33.6 billion in this period.[8] Over this period, it is also projected that ~150,000 fractures could be prevented, with an annual saving ranging from AU$140 million to AU$187 million.[8] The residual lifetime risk of osteoporotic fractures for women aged 50 years is estimated to be >40% and represent 80% of all fractures in the population over this age.[9] For men aged 60 years, the residual lifetime fracture risk is estimated to be ~30%.[10]

The most common sites of osteoporotic fractures are the hips, spine, and wrists. Hip fractures account for the majority of direct medical costs and are also an important contributor to long-term disability, with ~30% of older adults with a history of hip fracture not reaching their prefracture level of functioning 1 year following a fracture.[11] In addition to this, in the year following a hip fracture, there is a twofold increase in mortality,[12] estimated to be ~30%, and it is higher among male patients (37.5%).[13] Vertebral osteoporotic fractures are often asymptomatic, therefore escaping clinical diagnosis; however, when compared to other types of fragility fractures, they are associated with higher comorbidity, higher incidence of hospitalization, and longer hospital stays.[14] In addition, they have been strongly related to subsequent fractures and mortality.[14,15] The residual lifetime risk of vertebral osteoporotic fractures is 8.6% for men aged ≥45 years and 15.4% for women.[14] Distal radius fractures (occurring at the wrist) are more prevalent in women aged 45–65 years, and the most common mechanism of these fractures is direct trauma.[16] Although fractures of the distal radius are considered to cause the least morbidity of all fragility fractures, these fractures are regarded as an important predictor of subsequent fractures and mortality.[17]

Even though the majority (60–80%) of the variation in bone strength is attributed to genetics,[18–21] bone is considered a dynamic tissue, exhibiting continuous remodeling activity. This remodeling process is mediated by osteoblasts, which are cells responsible for bone formation, and osteoclasts, which are cells responsible for bone resorption, causing bone loss. The remodeling process is capable of adapting and responding to various stimuli.[22–24] On this basis, it is estimated that lifestyle and environmental factors, such as nutrition, alcohol intake, smoking, and skeletal loading, contribute to 20–40% of the variation in bone quality.[25] It is well known that prolonged periods of inactivity and unloading of the skeleton have a negative effect on bone mass, accelerating bone loss.[26] In addition, lean body mass and skeletal muscle mass are strongly related to bone mineral density (BMD).[27–29] It is also well documented that muscle contractions can increase loads on bones, generating stress and strain reactions in bone tissue,[30–32] and that dynamic loading has a more positive effect on bone tissue than static loading.[33]

Many efforts have been made to investigate nonpharmacological approaches for achieving an osteogenic (bone-producing) effect. It is well known that avoidance of tobacco and adequate serum levels of calcium and vitamin D are essential for bone health.[34–36] Physical activity has been shown to be an effective nonpharmacological approach to improve bone mass; however, not all types of exercise have been definitively shown to promote positive effects on bone metabolism.[37] In research to date, only impact weight bearing and high-impact progressive resistance training activities have a strong level of evidence indicating a positive osteogenic effect.[38–43] However, it is well known that aging can also be associated with physical decline, including conditions such as joint limitations and chronic pain, and, therefore, high-impact exercise is not always indicated or appropriate for middle-aged and older adults.

Exercise executed in the water environment, often referred to as water-based exercise (WBE), presents lower risks of traumatic fracture, and the joints are exposed to less stress and impact (via reduced loading due to buoyancy), when compared to land-based exercise (LBE), such as running, resistance training, and strength training. Besides this, WBE has been highly recommended for older people, especially those with disability, due to the reduced pain[44] and increased security it can provide,[45] in addition to providing additional benefits for neuromuscular and functional fitness,[45] and cardiometabolic health.[46] Furthermore, considering the potential for a reduction in the prevalence of pain and injuries, the dropout rate among subjects participating in WBE may be lower than that for some land-based activities. Finally, some older adults may simply enjoy WBE or wish to participate due to social reasons. In WBE, increased muscular demands are often necessary in order to overcome water resistance. For instance, Chevutschi et al[47] demonstrated that walking in water at an umbilical level increased the activity of the erector spinae and activated the rectus femoris to levels near to or higher than walking on dry ground. Therefore, considering the muscle demands and the dynamic component of WBE, there might be adequate stimulus to generate osteogenic stress and strain reactions in bones.

However, the literature is inconsistent in its reports of the effects of WBE on bone health of middle-aged and older adults. Some observational studies that have investigated swimmers have reported that participants have similar, or sometimes lower, BMD when compared to sedentary controls, indicating that swimming is associated with a similar or greater risk of bone deterioration and its consequences when compared to a sedentary lifestyle.[48–50] Velez et al[50] reported that mature-aged males who restricted their physical activity to only swimming had a 10% higher prevalence of osteoporosis when compared to sedentary age- and sex-matched controls. Conversely, in a cross-sectional analysis, Balsamo et al[51] concluded that aquatic exercise might be an effective nonpharmacological strategy to prevent bone loss in postmenopausal women. In addition to this, Gomez-Bruton et al[52] conducted a systematic review analyzing the effects of swimming on bone tissue, analyzing 64 studies assessing children, adolescents, adults, and elderly populations. It was reported that swimming had no negative influence on bone tissue and might have benefits on bone health later in life.

To date, a consensus regarding the effects of exercise practiced in water on bone health has not been reached, and a comprehensive literature search conducted by the authors identified no systematic review of the effects of WBE other than swimming. Therefore, the effects of exercise undertaken in a water environment on bone health of middle-aged and older adults remain uncertain.

This systematic review and meta-analysis aimed to answer the following question: is WBE effective in preventing age-related bone deterioration in middle-aged and older adults? The objective of the review was to assess the effect of WBE interventions in preventing age-related bone deterioration when compared to a sedentary lifestyle or other forms of exercise.

Findings of this systematic review and meta-analysis are expected to contribute to the knowledge of health-care professionals involved in this field with regard to the effectiveness of WBE, so that they can provide alternative recommendations regarding exercise types that can maintain or even enhance bone health and reduce the risk of fracture among their patients or clientele.

Methods

The review was conducted as a systematic review of relevant studies, incorporating both a critical narrative synthesis and a meta-analysis. The design of this study was guided by consideration of the Cochrane Handbook for Systematic Reviews of Interventions[53] and the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement.[54] The methods and eligibility criteria for included studies were detailed in advance in a protocol registered at the international database of prospectively registered systematic reviews in health and social care, PROSPERO[55] (registration number: CRD42015026685).

Eligibility criteria

To be included in the review, studies were required to be full-length research articles, published in academic journals or online (e-publication ahead of print), and no limits were set on language or date of publication. Only clinical trials (randomized [RCTs] or nonrandomized controlled trials) and prospective observational studies were considered for inclusion, with no limits set on length of follow-up. Studies were also considered only if they analyzed human subjects, either male or female, and if participants were aged 45 years or older, asymptomatic, and free living in the community. Participants in eligible studies could be healthy individuals or individuals with diagnosed osteopenia or osteoporosis; however, studies involving participants with other known health disorders or restrictions on participation in physical activities were ineligible. In addition, studies included in the systematic review were required to have a type of WBE or physical activity as the only intervention or exposure in at least one group and a comparison group, such as people undertaking other types of exercise or sedentary controls. If any medication or supplements were given to one group, the study was only considered if the medication or supplement was also given to all other groups, using the same dosage. Eligible studies assessed BMD by dual-energy X-ray absorptiometry (DEXA). The primary outcomes of interest in this review were BMD and bone mineral content (BMC) measured by DEXA, measured in at least one clinical site (lumbar spine [LS], proximal femur, total hip, or wrist); bone metabolism measured by serum biomarkers; incidence rates of bone fractures; minor adverse events, including falls; and serious adverse events, including death. The secondary outcomes of interest were muscle strength, flexibility, balance, and compliance with the intervention.

The following exclusion criteria were applied during study selection: publication types other than full-length journal articles, such as letters to the editor, conference abstracts, conference papers or book chapters; unpublished papers; studies using a descriptive or retrospective design; studies that did not evaluate human subjects; studies that did not evaluate middle-aged or older adults or that evaluated middle-aged or older adults together with other age groups without reporting the results separately; studies involving participants with medical disorders other than osteopenia or osteoporosis; studies that did not have WBE as the sole intervention in at least one group; studies that did not have a comparison group; studies that did not have BMD as an outcome; and studies that did not measure BMD by DEXA.

Search methods

To identify relevant studies, a multistep search was conducted in October 2015, without any limits on publication date, in the following databases: PubMed/MEDLINE, the Cochrane Library, EMBASE, SPORTDiscus, CINAHL, ScienceDirect, Scopus, AUSPORT, and PEDro. In addition, hand searches of reference lists of included articles were also performed to identify additional studies and data that met criteria for inclusion. The search strategy was kept as broad as possible, with identification of articles achieved by the use of specific text words, without using truncation, wildcards, or any other limits. Search strategies for all databases were tailored to the nuances of the respective database and are available upon request.

Data collection and analysis

Search results were imported into reference management software (EndNote),[56] where duplicate records were removed. Titles and abstracts were then screened, in order to exclude studies that were clearly ineligible. After initial screening, potentially eligible studies were retrieved for full-text eligibility assessment. The selection process applied to the full-text study reports was based upon the eligibility criteria discussed earlier, including types of interventions, types of outcome measures, types of participants, and types of studies. Disagreements regarding assessed eligibility were resolved by consensus and reasons for exclusion of studies were documented. The results of the entire search, screening, and selection process were recorded in a PRISMA diagram (Figure 1).[54]

Data were extracted and tabulated from all included papers using a standardized data extraction tool (The Cochrane Consumers and Communication Review Group).[53] Data extracted from each paper included specific details of title, authors, source, year of publication, study design, participants, the intervention, the comparison groups, length of follow-up, and data related to the primary and secondary outcomes of interest for this review.

Risk of bias was assessed for each included study using the Cochrane Collaboration's Risk of Bias tool.[57] The following elements that potentially affect risk of bias were addressed: random sequence generation (selection bias), allocation concealment (selection bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias), and other sources of bias (comparability of treatment and control group [CG] at entry, appropriateness of duration of follow-up). The risk of bias in the included studies was narratively described, and then each item was assigned a judgment: "low", "high," or "unclear" risk of bias. Nonrandomized controlled trials (quasi-experimental studies) and prospective observational studies were assessed and reported as being at a high risk of bias on the random sequence generation and allocation concealment items of the risk of bias tool.

Quantitative data were analyzed using the Cochrane software Review Manager (RevMan, version 5.3),[58] where outcomes were reported in at least two studies. Effect sizes for continuous outcomes were calculated as mean differences (MDs) or, if different scales had been used, as standardized mean differences (SMD), each with 95% confidence intervals (CIs), using a random-effects model. Missing data and attrition rates were assessed for each of the included studies and were reported as the proportion of commencing participants included in the final analysis. Intention-to-treat analysis of reported data from each included study was applied when extracting data for the meta-analysis. That is, each participant was included in the group to which they were randomized, and all randomized participants were included in the analysis. Heterogeneity was assessed using the standard χ^2 test and I^2 value.[53] Heterogeneity was considered statistically significant at $P < 0.10$. I^2 values between 0% and 30% were considered minimal, 30%–50% moderate, 50%–90% substantial, and >90% considerable. The overall treatment or intervention effect was calculated for each outcome measure in each included study. The effect of treatment or intervention on each outcome measure was calculated as the difference between the intervention and CGs in the change in measured outcome from baseline to the end of follow-up. For each outcome measure, variance was estimated based on the standard deviation (SD) of the MD between baseline and follow-up. When this value was not available and was not supplied by the respective study authors following a written request, we used the SD calculated from the P-value for the differences between mean values in the groups.[53] When the P-value was not available, we imputed the highest SD available from other studies included in the review.

Results

Search, screening, and selection results

The search of electronic databases retrieved 12,271 records, with an additional 25 articles identified by

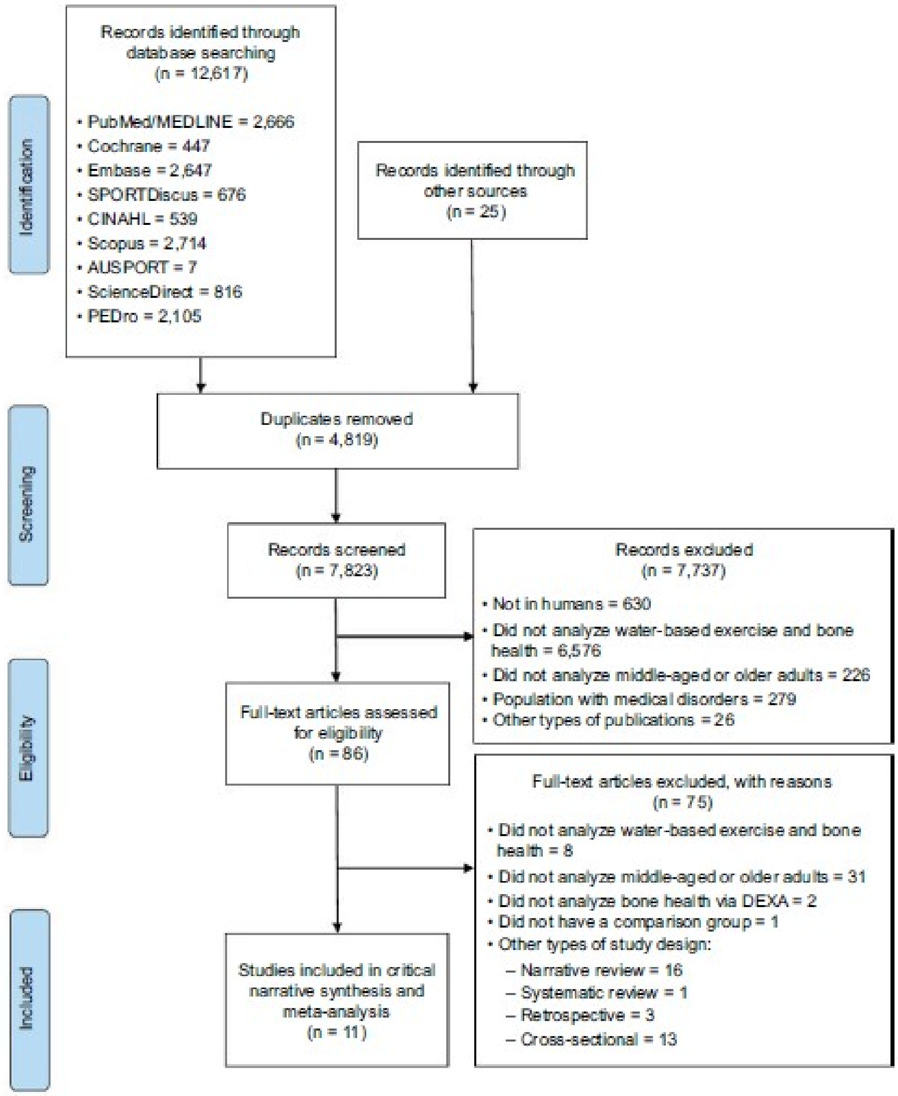

Figure 1 PRISMA flow diagram.
Abbreviation: PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analysis.

searching references of potentially eligible articles. After removing duplicates, 7,823 articles remained to be screened by title and abstract, with 7,737 of these being excluded because they clearly did not meet eligibility criteria and 86 articles then remaining to be assessed for eligibility in full text. From these full-text articles, 11 articles[59–69] that met eligibility criteria were identified and included in this review. Results from the search, screening, and selection processes are summarized in a PRISMA flow diagram (Figure 1).[54] Table 1 summarizes the characteristics of the 11 included studies.

Description of included studies

Of the 11 included studies, five were RCTs and six quasi-experiments (QEs). A total of 629 participants were divided into three groups: participants who performed WBE (n=344), participants who performed LBE (n=82), such as resistance training and strength training, and a sedentary

Table 1 General characteristics of included studies

Study ID	Design	Duration, months	Number of participants	Losses	Participants	Age, years
Borba-Pinheiro et al[59]	QE	12	35	NR	• Sex: females • Characteristics: women with osteoporosis/osteopenia, being treated with alendronate, no previous history of fractures and no history for at least 1 year of regular practice of PA, in good physical and mental health	45.6–64.5
Borba-Pinheiro et al[60]	QE	12	84	NR	• Sex: females • Characteristics: volunteers with osteoporosis and/or osteopenia in at least one of the DEXA measures, undergoing treatment with alendronate sodium (70 mg/week) and/or vitamin D, and no history of fractures, in good physical and mental health	49–61.8
Kemper et al[61]	RCT	6	30	7 (2 SWM/5 RTG)	• Sex: females • Characteristics: sedentary postmenopausal women	63.9 ± 6.49 (mean ± SD)
Moreira et al[62]	RCT	6	108	8 (5 AEG/3 CG)	• Sex: females • Characteristics: physical activity status classified as sedentary by the IPAQ short version questionnaire, postmenopausal for at least 5 years and cognitive function allowed to understand and respond to the authors' questions and commands during the questionnaires, no physical conditions that might affect performance during aquatic exercises; no chronic kidney disease; no history of recent hip fracture (in the last 2 years); no dependency on alcohol or illicit drugs; no chronic therapy with corticosteroids, bisphosphonates, calcitonin, calcium, vitamin D, and its metabolites; no use of estrogen, selective estrogen receptor modulators, and strontium in the earlier 6 months; no use of any medications that might interfere with vitamin D metabolism; systolic blood pressure <200 mmHg and/or diastolic blood pressure <100 mmHg	58.8 ± 6.4 (mean ± SD)
Murtezani et al[63]	RCT	10	64	3 (2 LBE/1 AE)	• Sex: females • Characteristics: women recently diagnosed (within the past 6 months) with osteoporosis on account of a DEXA scan T score below −2.5, aged 50–70 years, who had no history of vertebral fractures or lower extremity fractures, did not have endoprostheses or fixation materials and were capable of signing written informed consent	50–70

Water-based exercise	Comparison groups	BMD measurement	Secondary outcomes	Medications/ supplements	Adverse events	Compliance/ adherence
• Exercise: hydrogymnastics • Frequency: 3 times/week, 60 min, six bimonthly cycle • Intensity: Borg scale, 12 during the first 2 months and 14–16 during the rest of the study • Setting: 12 m section of a 25 m pool	• RTG • JUG • CG	• Equipment: DEXA Lunar DPX • Variables: BMD (g/cm²) • Regions: lumbar spine (L2–L4), neck of the femur, greater trochanter and Ward's triangle	• Body balance • Quality of life	Alendronate sodium 70 mg/week	NR	NR
• Exercises: hydrogymnastics • Frequency: three 60-min sessions per week on alternate days • Intensity: Borg scale, 11–12 during the first 2 months and 13–16 during the rest of the study • Setting: 12 m section of a 25 m pool	• CG	• Equipment: DEXA Lunar DPX • Variables: BMD (g/cm²) • Regions: lumbar spine (L2–L4), femoral neck and greater trochanter	• Quality of life	Alendronate sodium 70 mg/week and/or vitamin D3 5600 IU/week	NR	NR
• Exercises: swimming • Frequency: 3 days/week, 1 hour per session • Intensity: sessions began with moderate intensity activities (60% HRR) and reached high intensity activities (90% HRR) • Setting: pool with 1.50 m depth, and the water temperature during sessions remained between 27°C and 29°C	• RTG	• Equipment: DEXA Lunar DPX-IQ • Variables: BMD (g/cm²) • Regions: lumbar spine (L2–L4) and femoral neck	• Body composition	–	NR	>75% of sessions
• Exercises: hydrogymnastics • Frequency: 3 times/week, sessions lasted from 50 to 60 min • Intensity: level 6 in Borg scale (~60% of MHR) during 16 min of the session in weeks 5–9, level 7 in Borg scale (~70 % of MHR) during 13 min of the session in weeks 10–14, level 8 in Borg scale (~80 % of MHR) during 9 min of the session in weeks 15–19, and level 9 in Borg scale (~90 % of MHR), during 7 min of the session in weeks 20–24 • Setting: covered swimming pool, with depth varying between 1.10 and 1.30 m and water temperature between 30°C and 31°C	• CG	• Equipment: DEXA Hologic QDR • Variables: BMD (g/cm²) • Regions: lumbar spine (L1–L4), femoral neck, total femur, total body	• Biomarkers of bone turnover (iPTH, P1NP, and CTx)	Daily supplement of 500 mg of elementary calcium and 1,000 IU of vitamin D (cholecalciferol), combined in the same pill	NR	92.6% (95% CI, 85–98%
• Exercises: hydrogymnastics • Frequency: 3 times/week, 35 min • Intensity: participants were instructed to exercise at an intensity that was moderate to hard (12–14 on the 20-point Borg perceived exertion scale) • Setting: not stated (only reported that water temperature was 30°C)	• LBE	• Equipment: DEXA GE Lunar Prodigy • Variables: BMD (g/cm²) • Regions: lumbar spine (L2–L4)	• Muscle strength • Flexibility • Balance • Gait time • Pain	Ca (1,000 mg daily) and vitamin D (800–1,000 IU daily)	NR	NR

(Continued)

Table 1 (Continued)

Study ID	Design	Duration, months	Number of participants	Losses	Participants	Age, years
Novaes et al[64]	QE	6	31	NR	• Sex: females • Characteristics: living independently in the community, aged ≥55 years, postmenopausal status, being without contraindications to physical activity, and not reporting history of regular structured exercise	66.9 ± 6.1 (mean ± SD)
Pernambuco et al[65]	RCT	8	84	17 (6 AEG/11 CG)	Sex: females Characteristics: aged ≥60 years, with low BMD and no neurological disorders who did not exercise regularly for a minimum of 6 months prior to the study and did not suffer from metabolic or endocrine disorders	60–77
Rotstein et al[66]	QE	7	35	5 (all from intervention group)	Sex: females Characteristics: nonsmokers did not suffer from thyroid gland problems or hypertension and did not suffer from osteoporosis (baseline bone density was >55% of the mean bone density for the normal population of the subject's age), not taking any of the following medications: B complex, Betaxolol ophthalmic suspension, anastrozole, brotizolam, glucosamine, chondroitin, ofloxacin, atenolol, cilazapril, estradiol, norethisterone, pravastatin, losartan, amlodipine, and aspirin	50–65
Tsukahara et al[67]	QE	12	97	32 (7 from veterans group and 25 from newcomers group)	• Sex: females • Characteristics: healthy postmenopausal women	59.75–65.08
Vanaky et al[68]	RCT	3	20	NR	• Sex: females • Characteristics: nonsmoker females aged between 50 and 70 years; postmenopausal for at least 12 months; not institutionalized; and having no contraindication to undertake physical exercises without close medical supervision, hormone therapy, and calcium consumption and without cardiovascular and thyroid history	50–70
Wu et al[69]	QE	24	41		• Sex: females • Characteristics: postmenopausal	SWM – 59.5 ± 6.1 CG – 59.3 ± 5.2

Abbreviations: BMD, bone mineral density; QE, quasiexperiment; NR, not reported; RTG, resistance training group; JUG, judo group; CG, control group; DEXA, dual-energy X-ray absorptiometry; SWM, swimming group; HRR, heart rate reserve; SD, standard deviation; P1NP, procollagen type 1 amino-terminal propeptide; CTx, carboxy-terminal cross-linking telopeptide of type 1 collagen; AEG, aquatic exercises group; RCT, randomized controlled trial; BMC, bone mineral content; LBE, land-based exercise; ST, strength training ; CI, confidence interval; min, minutes; PA, physical activity; IPAQ, international physical activity questionnaire; AE, aquatic exercise; iPTH, intact parathyroid hormone; MHR, maximum heart rate.

Water-based exercise	Comparison groups	BMD measurement	Secondary outcomes	Medications/ supplements	Adverse events	Compliance/ adherence
• Exercises: hydrogymnastics • Frequency: 3 times/week, sessions lasting 45 min • Intensity: participants were instructed to attain 70%–80% of their work heart rate • Setting: public indoor swimming pool with a water depth of 1.20–1.40 m and a water temperature of 30.5°C	• ST	• Equipment: DEXA Hologic • Variables: BMD (g/cm²) • Regions: left femoral neck and lumbar spine (L1–L4)	–	–	–	>85%
• Exercises: hydrogymnastics • Frequency: twice weekly, 50 min • Intensity: not reported • Setting: swimming pool 25 m long and 1.40 m deep	• CG	• Equipment: DEXA Lunar DPX-L • Variables: BMD (g/cm²) • Regions: lumbar spine (L2–L4) and right total femur	• Bone formation (serum osteocalcin) • Functional autonomy	Volunteers with osteoporosis took alendronate sodium (70 mg) once a week and vitamin D3 once a day, while those with osteopenia used only vitamin D3	NR	NR
• Exercise: hydrogymnastics • Frequency: three 1 hour sessions per week • Intensity: 12–16 on Borg scale • Setting: pool, water temperature was 32°C, and all activities were conducted with the water at chest level	• CG	• Equipment: DEXA Lunar • Variables: BMD (g/cm²) and BMC (g) • Regions: lumbar spine (L2–L4) and femoral neck	–	–	NR	NR
• Exercise: hydrogymnastics and swimming • Frequency: once/week, 45 min/ session • Intensity: level of activity had two maximum working heart rate peaks (~120 beats/min) • Setting: sports club, warm water (28–29°C)	• Newcomers • CG	• Equipment: DEXA Hologic QDR • Variables: BMD (g/cm²) • Regions: lumbar spine (L1–L4)	–	–	NR	NR
• Exercise: hydrogymnastics • Frequency: 3 times/week, 1 h, 15 min/ session (after the second week) • Intensity: the intensity of the jumps was adjusted to ~60% of the HRR. During the second week, the intensity was increased to 80% of the HRR • Setting: pool	• CG	• Equipment: DEXA • Variables: BMD • Regions: lumbar spine (L2–L4) and femoral neck	• Functional fitness	–	NR	NR
• Exercise: swimming • Frequency: 1.5 times/week, 1 h/ session • Intensity: NR • Setting: pool	• CG	• Equipment: DEXA Norland • Variables: BMD (g/cm²) • Regions: lumbar spine (L1–L4) and proximal femur	• Leg extension power	–	–	–

CG (n=203). All participants in the studies were postmenopausal women. Four studies reported that the participants were previously sedentary.[59,61,62,64] Regarding bone health, four studies recruited participants with low BMD (osteopenia or osteoporosis)[59,60,63,65] and one recruited women with normal BMD.[66] Groups from one study received alendronate sodium,[59] groups from two studies received a combination of alendronate sodium and vitamin D,[60,65] and groups from another two studies received a combination of vitamin D and calcium.[62,63] The studies were conducted in Brazil (n=5),[59–62,65] Japan (n=2),[67,69] Kosovo (n=1),[63] Israel (n=1),[66] Iran (n=1),[68] and Portugal (n=1).[64] Nine studies were published in English,[59,60,62–68] one article was translated from Portuguese,[61] and one from Japanese.[69] The length of the exercise interventions varied in the included studies: one study conducted the intervention for 24 months,[69] three for 12 months,[59,60,67] one for 10 months,[63] one for 8 months,[65] one for 7 months,[66] three for 6 months,[61,62,64] and one for 3 months.[68] The frequency and duration of the sessions also varied in the included studies, ranging from once a week to three times a week, and each session lasted from 35 to 75 minutes. The content of the training sessions for WBE groups comprised hydrogymnastics in eight studies[59,60,62–66,68] and swimming in two studies.[61,69] One study combined both hydrogymnastics and swimming during the sessions.[67] Nine studies reported that exercise intensity was moderate to vigorous,[59–64,66–68] with the level of intensity determined by either heart rate or Borg scale. Four studies involved LBE groups as comparison groups, and the LBE training sessions consisted of resistance training,[59,61] strength training,[64] a mixture of aerobics and resistance training,[63] and judo.[59] Eight studies compared WBE to a sedentary CG.[59,60,62,65–69] One study included both WBE and LBE, as well as a CG.[59]

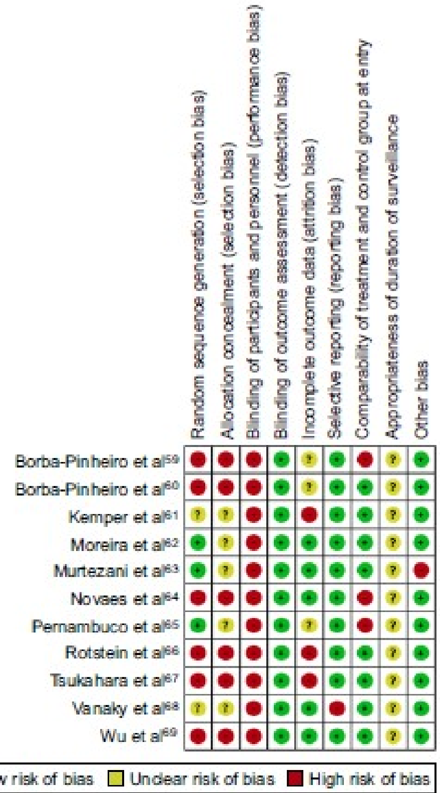

Figure 2 Risk of bias summary, by item and study.

Risk of bias in included studies

The judgment about each risk of bias item for each included study is presented in Figure 2, and the percentages of all included studies deemed to be at low risk, unclear risk, or high risk of bias based on each bias item are depicted in Figure 3.

Random sequence generation and allocation concealment (selection bias)

All nonrandomized studies (QE) were classified as "high risk" for both "random sequence generation" and "allocation concealment" items. Of the five RCTs included in the review, three reported adequate sequence generation and were classified as being at "low risk" of bias on this item.[62,63,65] The other two studies[61,68] reported that participants were randomized into groups; however, methods of randomization were not described and they were classified as being at "unclear risk" of bias on this item. None of the included RCTs described allocation concealment and so all were classified as being at "unclear risk" of bias for this item.

Blinding of participants and personnel (performance bias)

All studies were classified as being at "high risk" for performance bias, as none of the studies reported any attempt to blind participants and personnel (such as exercise instructors and researchers) to group allocations.

Blinding of outcome assessment (detection bias)

Considering the objective nature of the primary outcomes of interest, all studies were judged to be at "low risk" for detection bias.

Incomplete outcome data (attrition bias)

Five studies were considered to be at "low risk" of attrition bias as they either reported data for all participants or

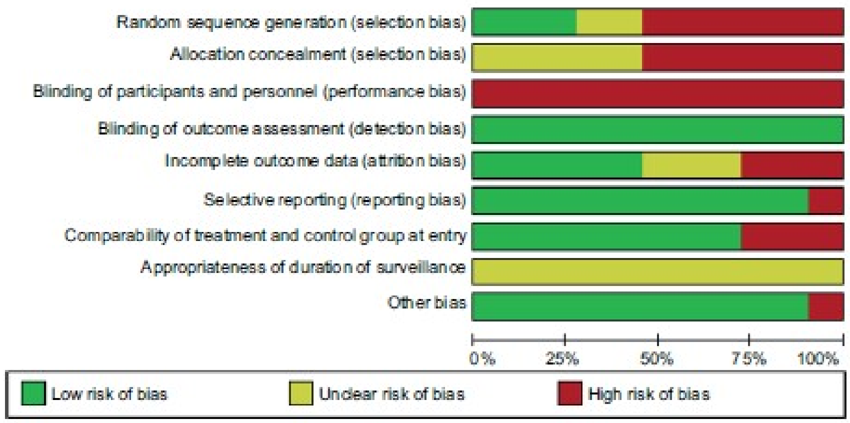

Figure 3 Risk of bias graph, by item.

appropriately addressed incomplete outcome data.[62–64,68,69] Three studies were judged to be at "unclear risk"[59,60,65] and three at "high risk".[61,66,67] The study conducted by Kemper et al[61] reported over 30% attrition for the LBE group and ~13% for the WBE group, and those lost to follow-up were not accounted for in the final analysis. Rotstein et al[66] reported 20% attrition in the WBE group, with no reasons mentioned, and again the analysis did not account for those lost to follow-up. In the study conducted by Tsukahara et al,[67] there was an attrition rate of over 62% in the WBE group, with no reasons mentioned and no adjustment of the analysis to account for the losses.

Selective reporting (reporting bias)

In all but one study, the primary outcome was reasonably well reported. Vanaky et al[68] reported their findings in a table that was poorly formatted and one of the reported results made no sense, and, therefore, this study was classified as presenting a "high risk" of reporting bias.

Comparability of groups at entry

Three studies[59,64,65] were judged to be at "high risk" of bias due to inadequate group comparability at entry. All other studies were judged to be at "low risk" of bias on this item.

Appropriateness of duration of follow-up

All studies were classified as being at "unclear risk" of bias stemming from lack of adequate duration of follow-up, as they only reported immediate postintervention data.

Other bias

In the study conducted by Murtezani et al,[63] the LBE group engaged in longer and more frequent training sessions than the WBE group. In the discussion section of that paper, it was mentioned that the WBE group exercised twice a week for 30 minutes, whereas the LBE group exercised thrice a week for 55 minutes. Therefore, this study was judged to be at "high risk" of bias due to the different doses of exercises provided to the groups. All other studies appeared to be free from other obvious sources of bias.

Primary outcomes

BMD

All studies reported BMD for at least one clinical site. All studies reported BMD for the LS, eight reported BMD for the femoral neck (FN),[59–62,64,66,68,69] four reported BMD for the greater trochanter (GT),[59,60,62,69] two reported BMD for Ward's triangle (WT),[59,69] and two reported BMD for the total femur (TF).[62,65]

LS BMD

LS BMD increased in participants performing WBE in 10 studies; however, this change was statistically significant in only one study.[68] Wu et al[69] reported a nonsignificant decrease in LS BMD in the WBE group. All eight studies that included a CG reported a nonsignificant decrease in LS BMD for this group.[59,60,62,65–69] Of the four studies reporting an LBE group, three reported a statistically significant increase in LS BMD in this group.[59,63,64] Kemper et al[61] reported a nonsignificant decrease. When comparing the results between groups, eight studies compared WBE and CG, and two described a statistically significant difference in change in LS BMD, in favor of the WBE group.[66,68] In the comparison between WBE and LBE, two studies described a statistically significant difference between these exercise types in effects on LS BMD, in favor of the LBE.[63,64] The results of a meta-analysis

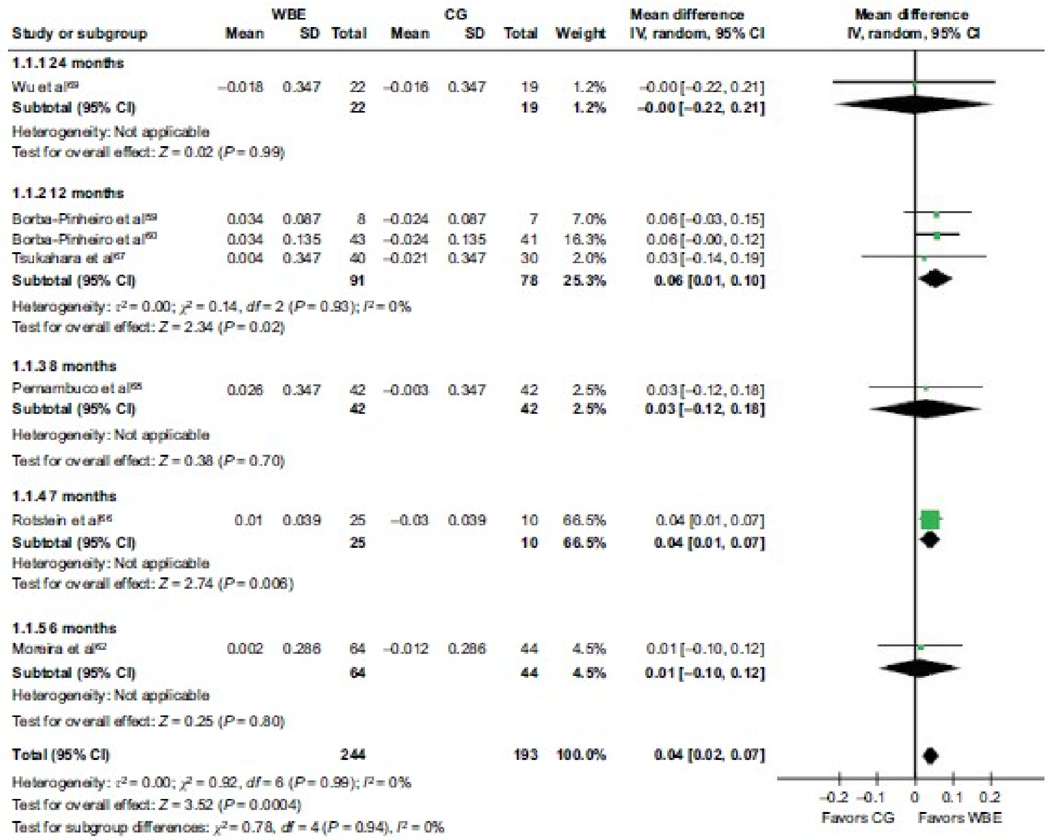

Figure 4 Forest plot of comparison between WBE and CG for changes in LS BMD (mean difference in g/cm²).
Abbreviations: WBE, water-based exercise; CG, control group; IV, inverse variance; LS, lumbar spine; BMD, bone mineral density; CI, confidence interval; SD, standard deviation.

comparing the effects of WBE and CG on LS BMD are shown in Figure 4. The results revealed a significant difference between the groups in favor of WBE (MD 0.04 g/cm²; 95% CI 0.02 to 0.07; $P = 0.0004$; $I^2 = 0\%$). In this meta-analysis, we excluded the study conducted by Vanaky et al,[68] due to its high risk of reporting bias, but a subsequent sensitivity analysis indicated that its inclusion in the analysis would not have affected the overall result anyway. For the comparison of the effects of WBE and LBE interventions on LS BMD, results revealed a significant difference between the interventions in favor of LBE (MD −0.04 g/cm²; 95% CI −0.06 to −0.02; $P < 0.00001$; $I^2 = 0\%$), as shown in Figure 5.

FN BMD

Of the eight studies that examined FN BMD, five reported an increase in this value for the WBE group;[61,62,66,68,69] however, only two studies reported a statistically significant change.[68,69] Two studies described a nonsignificant decrease in FN BMD in the WBE group,[59,60] and one study reported the same value at baseline and postintervention time points.[64] All six studies that assessed a CG reported a nonsignificant decrease in FN BMD in this sedentary group.[59,60,62,66,68,69] Of the three studies that assessed FN BMD in the LBE group, two studies described an increase,[59,64] which was statistically significant in one study,[64] and one study described a nonsignificant decrease.[61] When WBE was compared to CG, two studies reported statistically significant differences in FN BMD changes, in favor of WBE.[68,69] In the comparison between WBE and LBE, two studies reported statistically significant differences in FN BMD changes, in favor of LBE.[59,64] Figure 6 details the results of the meta-analysis comparing FN BMD changes in WBE and CG, showing that there was a statistically significant difference in favor of WBE (MD 0.03 g/cm²; 95% CI 0.01 to 0.05; $P = 0.001$; $I^2 = 0\%$). Once again, the study by Vanaky et al[68] was excluded in this meta-analysis, due to its high risk of reporting bias. In a subsequent

Study or subgroup	WBE Mean	WBE SD	WBE Total	LBE Mean	LBE SD	LBE Total	Weight	Mean difference IV, random, 95% CI
2.1.1 12 months								
Borba-Pinheiro et al[59]	0.034	0.084	8	0.091	0.084	9	4.3%	−0.06 [−0.14, 0.02]
Subtotal (95% CI)			**8**			**9**	**4.3%**	**−0.06 [−0.14, 0.02]**
Heterogeneity: Not applicable								
Test for overall effect: $Z = 1.40$ ($P = 0.16$)								
2.1.2 10 months								
Murtezani et al[63]	0.006	0.05	31	0.049	0.05	33	45.7%	−0.04 [−0.07, −0.02]
Subtotal (95% CI)			**31**			**33**	**45.7%**	**−0.04 [−0.07, −0.02]**
Heterogeneity: Not applicable								
Test for overall effect: $Z = 3.44$ ($P = 0.0006$)								
2.1.3 6 months								
Kemper et al[61]	0.005	0.084	15	−0.0002	0.084	15	7.6%	0.01 [−0.05, 0.07]
Novaes et al[64]	0.003	0.036	17	0.047	0.036	14	42.4%	−0.04 [−0.07, −0.02]
Subtotal (95% CI)			**32**			**29**	**50.0%**	**−0.03 [−0.07, 0.02]**
Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 2.18$, $df = 1$ ($P = 0.14$); $I^2 = 54\%$								
Test for overall effect: $Z = 1.17$ ($P = 0.24$)								
Total (95% CI)			**71**			**71**	**100.0%**	**−0.04 [−0.06, 0.02]**
Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 2.50$, $df = 3$ ($P = 0.48$); $I^2 = 0\%$								
Test for overall effect: $Z = 4.77$ ($P < 0.00001$)								
Test for subgroup differences: $\chi^2 = 0.53$, $df = 2$ ($P = 0.77$); $I^2 = 0\%$								

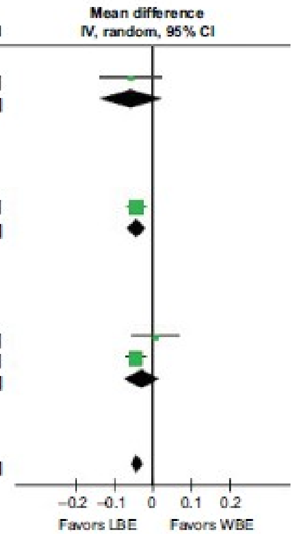

Figure 5 Forest plot of comparison between WBE and LBE for changes in LS BMD (mean difference in g/cm^2).

Abbreviations: WBE, water-based exercise; IV, inverse variance; LBE, land-based exercise; LS, lumbar spine; BMD, bone mineral density; CI, confidence interval; SD, standard deviation.

Study or subgroup	WBE Mean	WBE SD	WBE Total	CG Mean	CG SD	CG Total	Weight	Mean difference IV, random, 95% CI
1.2.1 24 months								
Wu et al[59]	0.029	0.049	22	−0.002	0.049	19	37.1%	0.03 [0.00, 0.06]
Subtotal (95% CI)			**22**			**19**	**37.1%**	**0.03 [0.00, 0.06]**
Heterogeneity: Not applicable								
Test for overall effect: $Z = 2.02$ ($P = 0.04$)								
1.2.2 12 months								
Borba-Pinheiro et al[59]	−0.007	0.104	8	−0.06	0.104	7	3.0%	0.05 [−0.05, 0.16]
Borba-Pinheiro et al[60]	−0.007	0.142	43	−0.06	0.142	41	9.1%	0.05 [−0.01, 0.11]
Subtotal (95% CI)			**51**			**48**	**12.1%**	**0.05 [0.00, 0.11]**
Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 0.00$, $df = 1$ ($P = 1.00$); $I^2 = 0\%$								
Test for overall effect: $Z = 1.97$ ($P = 0.05$)								
1.2.3 7 months								
Rotstein et al[66]	0.002	0.678	25	−0.023	0.678	10	0.1%	0.03 [−0.47, 0.52]
Subtotal (95% CI)			**25**			**10**	**0.1%**	**0.03 [−0.47, 0.52]**
Heterogeneity: Not applicable								
Test for overall effect: $Z = 0.10$ ($P = 0.92$)								
1.2.4 6 months								
Moreira et al[62]	0.01	0.067	64	−0.014	0.067	44	50.7%	0.02 [−0.00, 0.05]
Subtotal (95% CI)			**64**			**44**	**50.7%**	**0.02 [−0.00, 0.05]**
Heterogeneity: Not applicable								
Test for overall effect: $Z = 1.83$ ($P = 0.07$)								
Total (95% CI)			**162**			**121**	**100.0%**	**0.03 [0.01, 0.05]**
Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 0.95$, $df = 4$ ($P = 0.92$); $I^2 = 0\%$								
Test for overall effect: $Z = 3.22$ ($P = 0.001$)								
Test for subgroup differences: $\chi^2 = 0.95$, $df = 3$ ($P = 0.81$); $I^2 = 0\%$								

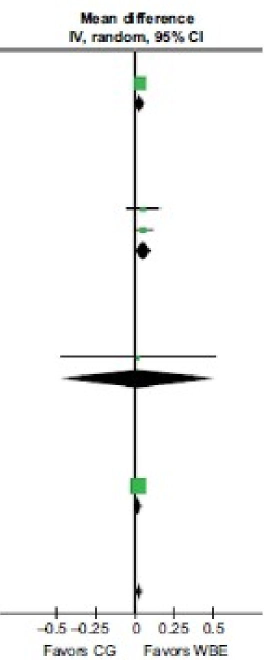

Figure 6 Forest plot of comparison between WBE and CG for changes in FN BMD (mean difference in g/cm^2).

Abbreviations: WBE, water-based exercise; CG, control group; IV, inverse variance; FN, femoral neck; BMD, bone mineral density; CI, confidence interval; SD, standard deviation.

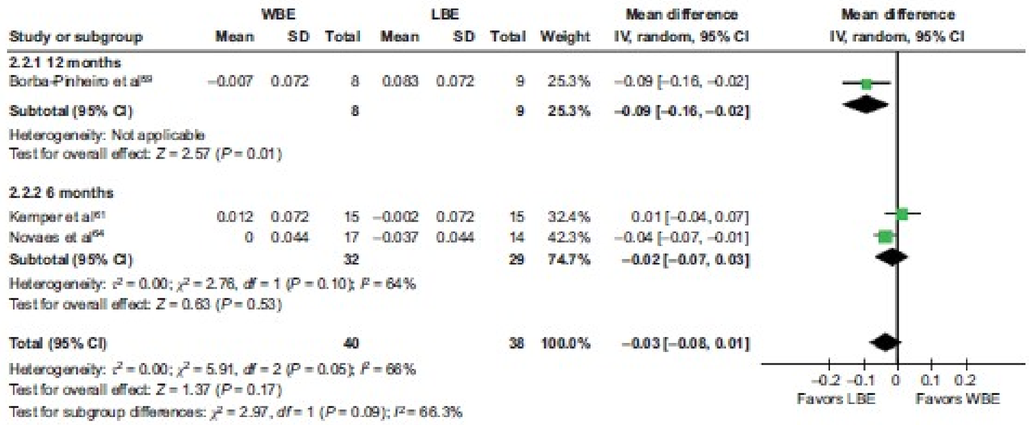

Figure 7 Forest plot of comparison between WBE and LBE for changes in FN BMD (mean difference in g/cm²).
Abbreviations: WBE, water-based exercise; IV, inverse variance; LBE, land-based exercise; FN, femoral neck; BMD, bone mineral density; CI, confidence interval.

sensitivity analysis, when this study was included, the results did not change, and heterogeneity was minimal ($I^2 = 14\%$, $P = 0.32$). In a further meta-analysis, there was no difference observed between WBE and LBE interventions in changes in FN BMD (MD −0.03 g/cm²; 95% CI −0.08 to 0.01; $P = 0.17$; $I^2 = 66\%$); however, heterogeneity was substantial ($P = 0.05$), as shown in Figure 7.

GT BMD

Of the four studies that examined GT BMD, three reported an increase in GT BMD in the WBE group,[59,60,69] and the change was statistically significant in one study.[69] The fourth study did not report a change in the GT BMD value in the WBE group.[62] Four studies reported changes in GT BMD in the CG. Three reported a decrease,[59,60,62] which was statistically significant in one,[62] and one reported a nonsignificant increase.[69] Three studies reported a statistically significant difference between the WBE and CG groups in changes in GT BMD, in favor of WBE.[60,62,69] Only one study described a change in GT BMD in the LBE group, reporting an increase, but no reference was provided to the statistical significance of the result,[59] and when LBE was compared to WBE with regard to changes in GT BMD, no statistical difference was found between the two groups. Meta-analysis was conducted to compare the effects of WBE and CG on GT BMD. The results revealed a statistically significant difference in favor of WBE (MD 0.04 g/cm²; 95% CI 0.00 to 0.07; $P = 0.05$; $I^2 = 86\%$), as detailed in Figure 8. In order to address the considerable heterogeneity among studies in this particular meta-analysis, we conducted a sensitivity analysis to examine the impact of removing from the analysis the study conducted by Moreira et al,[62] and the results were still in favor of WBE, with no heterogeneity then evident across the results (MD 0.05 g/cm²; 95% CI 0.03 to 0.07; $P < 0.00001$; $I^2 = 0\%$), as shown in Figure 9.

WT BMD

Two studies assessed changes in WT BMD in the WBE group, and both reported a nonsignificant increase following WBE.[59,69] The same studies reported WT BMD results for a CG, and both described a nonsignificant decrease. A statistically significant difference between WBE and CG in their effects on WT BMD was observed, in favor of the WBE group, in the study conducted by Wu et al.[69] One of the studies also described a change in WT BMD for an LBE group, reporting a nonsignificant increase in that group, and no differences between WBE and LBE in their effects on WT BMD.[59] Meta-analysis revealed a significant difference between WBE and CG in their effects on WT BMD (MD 0.04 g/cm²; 95% CI 0.00 to 0.08; $P = 0.04$; $I^2 = 0\%$), as presented in Figure 10.

TF BMD

Two studies described changes in TF BMD in a WBE group and a CG, reporting nonsignificant increases in TF BMD following WBE and nonsignificant decreases in TF BMD in the CG.[62,65] No significant differences were reported between these groups, and no significant differences were found in the results of a meta-analysis (MD 0.02 g/cm²; 95% CI −0.01 to 0.05; $P = 0.15$; $I^2 = 0\%$), as detailed in Figure 11.

BMC

Only one study reported BMC as an outcome measure.[66] Change in BMC was described for both LS and FN, in both WBE and CG. The authors reported a nonstatistically

Study or subgroup	WBE Mean	WBE SD	WBE Total	CG Mean	CG SD	CG Total	Weight	Mean difference IV, random, 95% CI
1.3.1 24 months								
Wu et al[63]	0.036	0.038	22	−0.021	0.038	19	31.3%	0.06 [0.03, 0.08]
Subtotal (95% CI)			**22**			**19**	**31.3%**	**0.06 [0.03, 0.08]**
Heterogeneity: Not applicable								
Test for overall effect: $Z = 4.79$ ($P < 0.00001$)								
1.3.2 12 months								
Borba-Pinheiro et al[59]		0.13	8	−0.029	0.13	7	6.0%	0.05 [−0.08, 0.18]
Borba-Pinheiro et al[60]		0.082	43	−0.029	0.082	41	26.7%	0.05 [0.01, 0.08]
Subtotal (95% CI)			**51**			**48**	**32.7%**	**0.05 [0.01, 0.08]**
Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 0.00$, $df = 1$ ($P = 1.00$); $I^2 = 0\%$								
Test for overall effect: $Z = 2.72$ ($P = 0.007$)								
1.3.3 6 months								
Moreira et al[62]	0	0.012	64	−0.008	0.012	44	36.0%	0.01 [0.00, 0.01]
Subtotal (95% CI)			**64**			**44**	**36.0%**	**0.01 [0.00, 0.01]**
Heterogeneity: Not applicable								
Test for overall effect: $Z = 3.40$ ($P = 0.0007$)								
Total (95% CI)			**137**			**111**	**100.0%**	**0.04 [0.00, 0.07]**
Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 20.85$, $df = 3$ ($P = 0.0001$); $I^2 = 86\%$								
Test for overall effect: $Z = 2.00$ ($P = 0.05$)								
Test for subgroup differences: $\chi^2 = 20.85$, $df = 2$ ($P < 0.0001$); $I^2 = 90.4\%$								

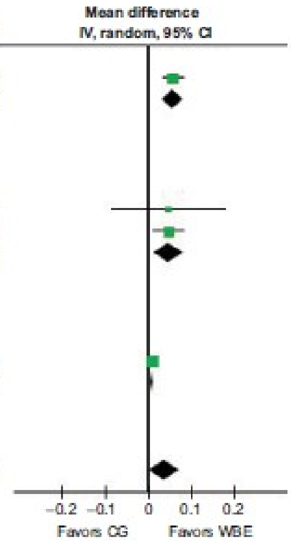

Figure 8 Forest plot of comparison between WBE and CG for changes in GT BMD (mean difference in g/cm²).
Abbreviations: WBE, water-based exercise; CG, control group; IV, inverse variance; GT, great trochanter; BMD, bone mineral density; CI, confidence interval; SD, standard deviation.

Study or subgroup	WBE Mean	WBE SD	WBE Total	CG Mean	CG SD	CG Total	Weight	Mean difference IV, random, 95% CI
1.3.1 24 months								
Wu et al[63]	0.036	0.038	22	−0.021	0.038	19	67.9%	0.06 [0.03, 0.08]
Subtotal (95% CI)			**22**			**19**	**67.9%**	**0.06 [0.03, 0.08]**
Heterogeneity: Not applicable								
Test for overall effect: $Z = 4.79$ ($P < 0.00001$)								
1.3.2 12 months								
Borba-Pinheiro et al[59]	0.018	0.13	8	−0.029	0.13	7	2.1%	0.05 [−0.08, 0.18]
Borba-Pinheiro et al[60]	0.018	0.082	43	−0.029	0.082	41	30.0%	0.05 [0.01, 0.08]
Subtotal (95% CI)			**51**			**48**	**32.1%**	**0.05 [0.01, 0.08]**
Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 0.00$, $df = 1$ ($P = 1.00$); $I^2 = 0\%$								
Test for overall effect: $Z = 2.72$ ($P < 0.007$)								
Total (95% CI)			**73**			**67**	**100.0%**	**0.05 [0.03, 0.07]**
Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 0.23$, $df = 2$ ($P = 0.89$); $I^2 = 0\%$								
Test for overall effect: $Z = 5.49$ ($P < 0.00001$)								
Test for subgroup differences: $\chi^2 = 0.23$, $df = 1$ ($P = 0.063$); $I^2 = 0\%$								

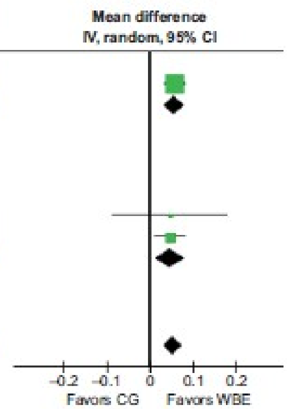

Figure 9 Forest plot of comparison between WBE and CG for changes in GT BMD (Moreira et al[62] excluded; mean difference in g/cm²).
Abbreviations: WBE, water-based exercise; CG, control group; IV, inverse variance; GT, great trochanter; BMD, bone mineral density; CI, confidence interval; SD, standard deviation.

significant increase in BMC at both these sites in the WBE group and a nonstatistically significant decrease in BMC at both sites in the CG group. In the comparison between these groups, both LS and FN BMC increased significantly more in the WBE group than in the CG.

Bone metabolism

Two studies included bone metabolism as an outcome measure,[62,65] and both compared the WBE results to results of a CG. Moreira et al[62] analyzed the biomarker of bone formation, procollagen type 1 amino-terminal propeptide (P1NP), and the biomarker of bone resorption, carboxy-terminal cross-linking telopeptide of type 1 collagen (CTx), comparing the effects of WBE and CG on these biomarkers. The authors reported a mean increase in P1NP in both groups; however, the increase was statistically significant only in the WBE group. In the comparison between groups for P1NP, the effect on P1NP was significantly greater in the WBE group. The bone resorption biomarker CTx was observed to increase in both WBE and CG, but this increase reached statistical significance only in the CG, and no differences were found between these groups in their effects on CTx.

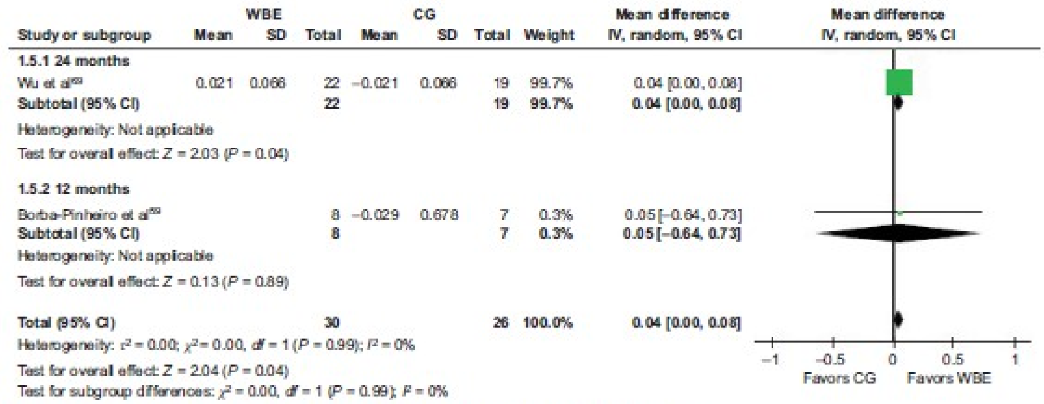

Figure 10 Forest plot of comparison between WBE and CG for changes in WT BMD (mean difference in g/cm²).
Abbreviations: WBE, water-based exercise; CG, control group; IV, inverse variance; WT, Ward's triangle; BMD, bone mineral density; CI, confidence interval; SD, standard deviation.

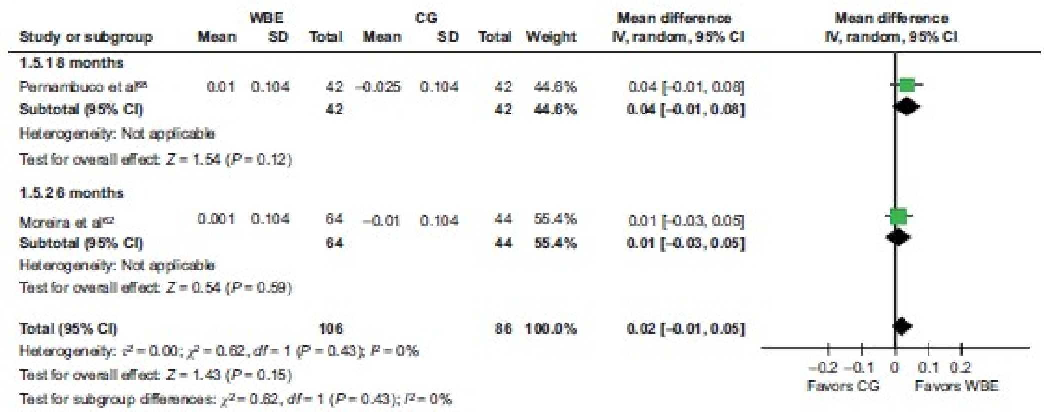

Figure 11 Forest plot of comparison between WBE and CG for changes in TF BMD (mean difference in g/cm²).
Abbreviations: WBE, water-based exercise; CG, control group; IV, inverse variance; TF, total femur; BMD, bone mineral density; CI, confidence interval; SD, standard deviation.

In the study conducted by Pernambuco et al,[65] the authors analyzed the biomarker of bone formation, osteocalcin. They reported a statistically significant increase in osteocalcin levels in the WBE group and a nonsignificant decrease in the CG. The mean increase in osteocalcin levels following WBE was significantly greater than that in the CG. Meta-analysis revealed significant differences between WBE and CG in favor of WBE for changes in the biomarkers of bone formation (SMD 0.49; 95% CI 0.20 to 0.78; $P = 0.0008$; $I^2 = 0\%$), as presented in Figure 12.

Adverse events

Only three of the included studies reported information about adverse events. One of the studies reported that neither WBE group nor LBE group participants experienced fractures or serious orthopedic problems.[63] In that study,[63] one individual allocated to the LBE group withdrew due to injury; however, it is not clear if the injury was associated with the exercise intervention. In another study, it was reported that no injuries were experienced by the participants in the WBE group.[62] In the study conducted by Kemper et al,[61] one individual was excluded due to chest pain during the WBE sessions. None of these three studies included fracture rate as an outcome, and no other study reported data regarding adverse events.

Secondary outcomes

Muscle strength

Two studies assessed muscle strength as an outcome.[63,69] Murtezani et al[63] assessed right-hand grip strength (GS), and right quadriceps strength (QS), and compared WBE to LBE. Both groups improved significantly in grip strength and QS; however, observed improvements following LBE were

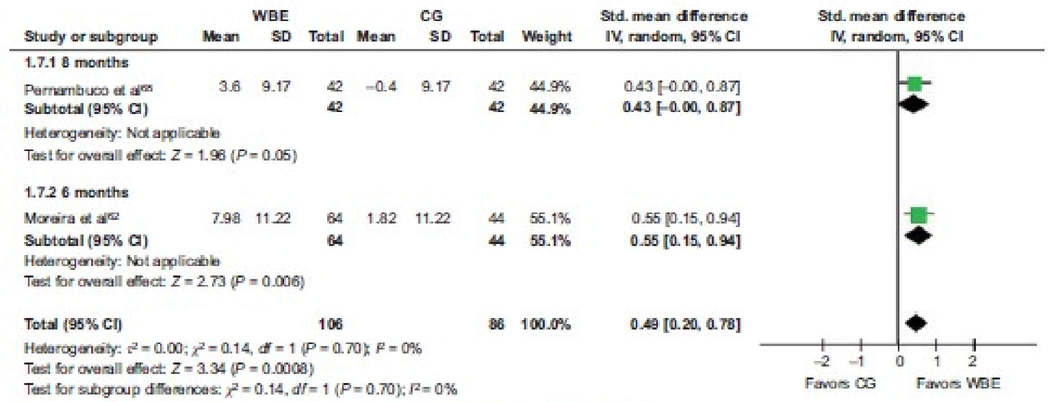

Figure 12 Forest plot of comparison between WBE and CG for changes in biomarkers of bone formation.
Abbreviations: WBE, water-based exercise; CG, control group; IV, inverse variance; CI, confidence interval; SD, standard deviation.

significantly greater than those observed following WBE, for both outcomes. Wu et al[69] reported QS changes, comparing the results of WBE to a CG. The WBE was associated with a statistically significant increase in QS, whereas the CG was associated with a nonsignificant decrease, with no information provided about the level of statistical difference in this outcome between groups.

Flexibility

No studies provided data on changes in participant flexibility associated with WBE. One study reported flexibility as an outcome,[63] using the "bend reach performance test". This study compared the WBE group to an LBE group, and the authors reported a statistically significant improvement in flexibility in the LBE group; however, no results were reported for the WBE group.

Balance

Balance outcomes of participants were reported in two studies.[59,63] Both studies reported balance results for WBE and LBE, and one also provided results for a CG.[59] Borba-Pinheiro et al[59] assessed body balance using the Static Balance Test with Visual Control. Both WBE and LBE groups improved in their balance ability following the respective type of exercise, and the CG group decreased in balance ability; however, no information regarding statistical significance of these changes in balance within groups was reported. When the balance results of the WBE group were compared to those for LBE and CG, the differences in balance outcomes were not statistically significant. Murtezani et al[63] assessed balance using the Berg Balance Scale and reported positive changes in balance following WBE and LBE, which reached statistical significance for the latter; however, no differences in balance outcomes were found between the WBE and LBE groups. Meta-analysis was conducted to compare effects of WBE and LBE on balance outcomes, and no statistically significant difference was found between the interventions (SMD −0.31; 95% CI −0.75 to 0.13; $P = 0.17$; $I^2 = 0\%$), as detailed in Figure 13.

Compliance

Only two studies reported levels of exercise compliance for both WBE and LBE groups.[61,64] Kemper et al[61] described an attendance rate of >75% of the sessions in both WBE and LBE groups, and Novaes et al[64] described an attendance rate of >85% of the sessions in both groups.

Discussion

The main goal of the present systematic review was to determine the effects of WBE on bone health of middle-aged and older adults and to compare these WBE effects to those observed in a sedentary CG or LBE group. To the best of our knowledge, this is the first systematic review and meta-analysis addressing this topic. The main finding of the present systematic review supports the hypothesis that WBE may reduce age-related bone deterioration, as we identified statistically significant differences between WBE and CG in their effects on bone health, in favor of WBE. At the same time, the analyses also substantiate the belief that LBE is more effective than WBE in promoting positive changes in the bone tissue.

The importance of this review lies in the fact that medical and health/fitness professionals should be able to provide recommendations regarding effective alternatives among

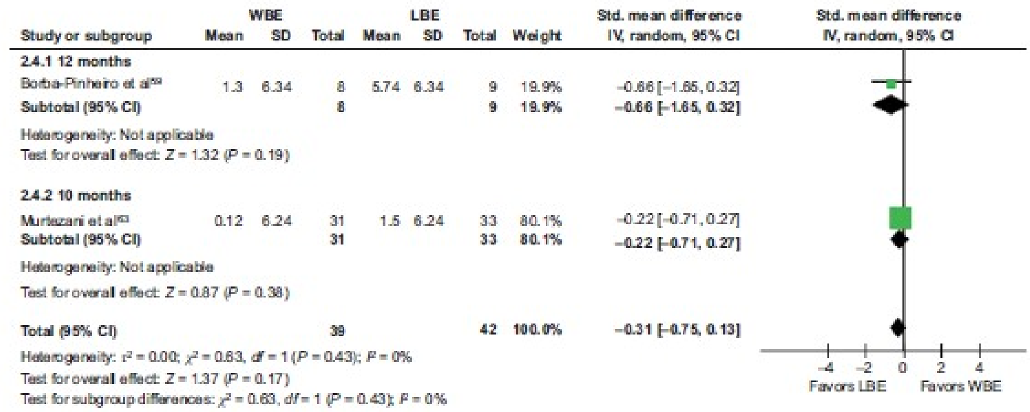

Figure 13 Forest plot of comparison between WBE and LBE for changes in body balance.
Abbreviations: WBE, water-based exercise; IV, inverse variance; LBE, land-based exercise; CI, confidence interval; SD, standard deviation.

exercise interventions, in order to keep the population physically active, preventing the bone loss associated with the aging process and subsequent increased risk of fracture. The findings of this review are consistent with findings of the systematic review conducted by Gomez-Bruton et al,[52] which investigated the effects of swimming in different age groups and revealed that WBE may have a positive impact on bone health in later adulthood. However, that review was limited to swimming, and the authors also concluded that the participants in the WBE had lower BMD than participants in land-based sports.

In the meta-analysis reported in this review comparing the effects of WBE to those of CG on LS BMD, the study conducted by Wu et al[69] was the only study that reported bone loss in both WBE and CG groups at this clinical site (Figure 4). However, the decrease in BMD described in that study did not reach statistical significance within either group, and no significant difference was evident between groups. As described in Table 1, the type of WBE used in this QE[69] was swimming, and the intervention was conducted 1.5 times per week for 24 months, with no information included pertaining to the duration and intensity of the sessions. It is, therefore, impossible to ascertain the actual dose of swimming received by participants, which may have been too low to have an effect on bone metabolism. As can be seen from Figure 4, the study having the greatest weight in this particular meta-analysis was the study conducted by Rotstein et al.[66] The WBE in that QE was hydrogymnastics, conducted three times per week for 7 months, in sessions of moderate to vigorous intensity, each lasting 60 minutes and involving participants who were postmenopausal women with normal BMD (Table 1). Thus, it could be argued that interventions lasting >6 months, with sessions of similar intensity and duration to those described by Rotstein et al,[66] are likely to have positive effects on LS BMD. As shown in Figure 4, two RCTs were included in this particular meta-analysis focused on comparing the effects of WBE and CG on LS BMD,[62,65] and due to relative study weightings, these two RCTs contributed just 2.5% and 4.5% of the overall effect determined by the meta-analysis. The minor contribution of these RCTs is attributed to the relatively high SD associated with each. These values were obtained indirectly for both these RCTs, as we could not obtain SD values from the reported results, and contact with authors was not successful. As we chose a conservative approach to estimate the SD, the real value might be lower than the one used in our analysis, and this would influence the impact of each study on the outcome of the meta-analysis, but not the overall observed effect. The same interpretation applies to the small contribution of the study conducted by Wu et al[69] in this particular meta-analysis.

In the meta-analysis comparing the effects of WBE and LBE on LS BMD, it is worth noting that all four studies included in the meta-analysis reported a nonsignificant increase in LS BMD in the WBE group, and three reported a statistically significant increase in LS BMD in the LBE group (Figure 5). Surprisingly, the RCT conducted by Kemper et al[61] reported a nonsignificant decrease in LS BMD in the LBE group, which performed resistance training as the LBE intervention, while swimming was the WBE intervention (Table 1). The LBE and WBE sessions were conducted three times per week, in moderate to vigorous sessions of 60 minutes, for 6 months. The dose of the swimming intervention may explain the difference between the results reported by Kemper et al[61] and by Wu et al[69] for swimming as a type of WBE – where Kemper et al[61] observed a nonsignificant increase in LS BMD following the swimming intervention, Wu et al,[69] who used a possibly much lower dose of swimming, observed a nonsignificant decrease. As depicted in Figure 5, two studies contributed with similar impact to this meta-analysis comparing effects of WBE and LBE on LS BMD, with respective weightings of 45.7% and 42.4% in the meta-analysis, attributed to their relatively small SD for this outcome.[63,64] The first was an RCT conducted by Murtezani et al[63] over 10 months, in which women with low BMD who were prescribed alendronate sodium and vitamin D were recruited (Table 1). The authors reported statistically significant differences between the groups in the observed changes in LS BMD, in favor of LBE; however, the differences reported might be explained by the fact that the exercise sessions were more frequent and lasted longer for individuals in the LBE group, with this LBE group, therefore, receiving a higher dose of exercise. The other study was conducted by Novaes et al[64] and was a QE conducted over 6 months, with exercise occurring three times per week, in sessions of 45 minutes of moderate to vigorous intensity (Table 1). These authors also reported statistically significant differences between the WBE and LBE groups in favor of LBE. Of note in the comparison between WBE and LBE with regard to their effects on LS BMD is that the study by Borba-Pinheiro et al[59] is the only study in which the WBE intervention was conducted for >6 months, and the WBE involved sessions of moderate to vigorous intensity lasting 60 minutes. In that study, there was no statistically significant difference observed between the groups in changes in LS BMD, and this finding might be explained by the small sample size, which also influenced the study's minor contribution to the overall effect observed in the meta-analysis (Figure 5).

In the comparison between WBE and CG with regard to their effects on FN BMD, the study conducted by Moreira et al[62] had a weighting of 50.7% in the meta-analysis, as a consequence of the small SD for this outcome measure (Figure 6). As detailed in Table 1, this RCT was conducted over 6 months, analyzing the effects of hydrogymnastics on bone health of previously sedentary women who were prescribed calcium and vitamin D. The WBE sessions were of moderate to vigorous intensity, conducted three times a week and lasted between 50 and 60 minutes. This study did not detect a statistically significant difference between WBE and CG in their effects on FN BMD, and a possible explanation for this finding might be the fact that the intervention was limited to 6 months. In the comparison of the effects of WBE and LBE on FN BMD, the results are limited by substantial heterogeneity, as shown in Figure 7. The QE conducted by Novaes et al[64] contributed with a weighting of 42.3% to this meta-analysis, and the authors reported a statistically significant difference between the WBE and LBE groups, in favor of the LBE group. The exercise sessions of both groups lasted 45 minutes and involved moderate to vigorous intensity exercise, three times per week, and follow-up was limited to 6 months (Table 1). The RCT conducted by Kemper et al[61] contributed to increase the heterogeneity in the assessment of the overall effect of WBE when compared to LBE in this particular meta-analysis, as this study had contradictory results when compared to the other two studies included in the meta-analysis. The exercise sessions lasted 60 minutes and involved moderate to vigorous intensity exercise, conducted three times per week for 6 months, and the authors reported a nonsignificant increase in FN BMD in the WBE group and a nonsignificant decrease in the LBE group, with no differences found between the groups. Once again, these findings are consistent with the notion that WBE interventions conducted for a period of >6 months, in sessions of at least 60 minutes of moderate to high intensity and conducted three times per week, could possibly have a benefit to bone health. This hypothesis is also supported by the results reported for GT (Figures 8 and 9), WT (Figure 10), and TF (Figure 11); however, it was only possible to compare WBE to CG in the analysis of these three clinical sites.

Interestingly, Moreira et al[62] reported that both WBE and CG participants had a statistically significant increase in the biomarker of bone resorption CTx, although no differences were found between these groups. Those authors reported that levels of CTx typically increase in initial stages of the postmenopausal period, which was the case for the participants included in both groups. As shown in Figure 13, the RCT conducted by Murtezani et al[63] contributed with a weighting of 80% in the meta-analysis comparing the effects of WBE and LBE on balance ability, with this weighting being a consequence of the large sample size in that study. However, it is important to note that in that study the LBE group engaged in more frequent and longer exercise sessions than the WBE group. For measures of muscle strength and flexibility, no meta-analyses were conducted due to lack of studies reporting comparisons of these outcomes. The study of Murtezani et al[63] was the only one to report statistically significant differences between WBE and LBE for both these outcomes, each in favor of LBE, but once again it is important to highlight the differences between the LBE and WBE interventions used in this study, in terms of the frequency and duration of the exercise sessions discussed earlier. The findings of the present review regarding effects of WBE on muscle strength and balance ability are in line with results of previous studies, which have demonstrated that individuals participating in WBE achieved a statistically significant improvement in both outcomes.[45,70–72] The studies conducted by Bergamin et al[70] and Oh et al[71] also reported a statistically significant improvement in flexibility for participants in WBE.

Only three studies included in the present review reported information regarding adverse events; however, due to lack of adequate reporting, no definitive conclusions can be drawn in this regard.

One of the strengths of this review is the comprehensive search of published studies, which was not limited by language of publication. This allowed us to include in the analyses two studies published in languages other than English, eliminating language bias in the review. For the meta-analyses, we used the random-effects model, as this enabled the researchers to estimate the mean effect across a range of studies in a manner that meant none of the individual studies could overly influence the overall estimate of effect. However, limitations should be highlighted. The generally low quality of available studies and the inclusion of QE in the meta-analyses mean that the results should be interpreted with caution. Another limitation is that none of the included studies reported the SD for the mean change in BMD. This value is necessary in order to conduct meta-analyses of the results, and so this value was estimated for each group. This estimate was derived for each study by either calculating the SD based on the reported *P*-value or by imputing the largest SD for that specific outcome that was reported in other studies. This approach was decided in order to achieve more conservative results but may have therefore also limited some of the effect sizes estimated in the meta-analyses. No study investigating a male population was found or included in this review, and so further research involving male participants is needed. It should also be noted that this review was purposely limited to investigating effects of WBE on bone health of middle-aged and older adults, and so the results should not be extrapolated to younger populations. While it is possible that publication bias may have affected the findings of this review, inspection of funnel plots developed to assess this likelihood suggested that it probably had little impact on the results.

Conclusion

The results of this study corroborate the widely held belief that WBE is not as effective as LBE for enhancing bone health but they also indicate that, when the exercise dose is sufficient, WBE is better for bone health than a sedentary lifestyle in middle-aged and older adults. In order to increase exercise participation in middle-aged and older adults, it may be important to focus on alternative modes of exercise that are both suitable and feasible for this population, and which take into account possible clinical limitations of the individual and personal preferences. The results of the present meta-analyses indicate that an adequate dose of WBE may be a useful alternative to LBE, as it appears to decrease the rate of age-related bone loss in postmenopausal women. Moreover, it can increase BMD in this population, and it was demonstrated to have positive impacts on both bone metabolism and muscle strength.

There is currently not sufficient evidence to form a basis for recommending any specific WBE intervention when aiming to improve bone health; however, the results of this review suggest that WBE of higher intensity, frequency, and session duration, sustained over many months, is likely to be the most beneficial. Importantly, the findings of this review cannot be extrapolated to a male population since all participants in included studies were postmenopausal women, and they should not be extrapolated to younger populations, since the review was designed to focus only on middle-aged and older participants.

Further well-designed RCTs, including both males and females, should be undertaken to investigate the effects of WBE on bone health of middle-aged and older adults and to compare the effects of different types of WBE. Based on our findings, it appears that future interventions should be designed to last at least 12 months, and that the WBE sessions should be of moderate to vigorous intensity and at least 60 minutes in duration, occurring at least three times a week. With respect to BMD results, future research should adequately report SDs for the mean change within groups in this outcome measure, along with its *P*-value, in order to enable correct interpretation of the effect size of the results.

Disclosure

The authors report no conflicts of interest in this work.

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Appendix II: PubMed/MEDLINE search strategy (Chapter 3)

1. "surf"
2. "surfer"
3. "surfers"
4. "surfing"
5. "surfboard"
6. "surfboards"
7. "surfboarding"
8. "surfboardriding"
9. "longboard"
10. "longboards"
11. "longboarder"
12. "longboarders"
13. "bodyboarding"
14. "bodyboard"
15. "bodyboards"
16. "bodyboarder"
17. "bodyboarders"
18. "skimboarding"
19. "skimboard"
20. "skimboards"
21. "skimboarder"
22. "skimboarders"
23. "wakeboarding"
24. "wakeboard"
25. "wakeboards"
26. "wakeboarder"
27. "wakeboarders"
28. "kitesurf"
29. "kitesurfboarding"
30. "kitesurfboard"
31. "kitesurfboards"
32. "kitesurfboarder"
33. "kitesurfboarders"
34. "kitesurfing"
35. "kitesurfer"
36. "kitesurfers"
37. "windsurf"
38. "windsurfing"
39. "windsurfboard"
40. "windsurfboards"
41. "windsurfboarding"
42. "windsurfer"

43. "windsurfers"
44. "sailboarding"
45. "sailboard"
46. "sailboards"
47. "sailboarder"
48. "sailboarders"
49. (("stand up" OR "stand-up") AND "paddle")
50. "paddling"
51. "paddle"
52. "paddler"
53. "paddlers"
54. "rowing"
55. "rower"
56. "rowers"
57. "canoe"
58. "canoeing"
59. "canoeist"
60. "canoeists"
61. "sailing"
62. "sailboard"
63. "sailboards"
64. "sailor"
65. "sailors"
66. "dragon-boat"
67. "dragon-boats"
68. "dragon-boating"
69. "dragon boat"
70. "dragon boats"
71. "dragon boating"
72. "kayak"
73. "kayaking"
74. "kayaker"
75. "kayakers"
76. "swim"
77. "swimming"
78. "swimmer"
79. "swimmers"
80. "water polo"
81. "snorkel"
82. "snorkeling"
83. "hydrotherapy"
84. "hydrotherapies"

85. "hydro-therapy"
86. "hydro-therapies"
87. "hydro therapy"
88. "hydro therapies"
89. "hydrogymnastic"
90. "hydrogymnastics"
91. "hydro gymnastics"
92. "hydro-aerobic"
93. "hydro-aerobics"
94. "hydro aerobic"
95. "hydro aerobics"
96. "water aerobics"
97. "water aerobic"
98. "aqua aerobic"
99. "aqua aerobics"
100. "Hydrotherapy"[Mesh]
101. 1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 OR 9 OR 10 OR 11 OR 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18 OR 19 OR 20 OR 21 OR 22 OR 23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29 OR 30 OR 31 OR 32 OR 33 OR 34 OR 35 OR 36 OR 37 OR 38 OR 39 OR 40 OR 41 OR 43 OR 44 OR 45 OR 46 OR 47 OR 48 OR 49 OR 50 OR 51 OR 52 OR 53 OR 54 OR 55 OR 56 OR 57 OR 58 OR 59 OR 60 OR 61 OR 62 OR 63 OR 64 OR 65 OR 66 OR 67 OR 68 OR 69 OR 70 OR71 OR 72 OR73 OR 74 OR75 OR 76 OR 77 OR 78 OR 79 OR 80 OR 81 OR 82 83 OR 84 OR 85 OR 86 OR 87 OR 88 OR 89 OR 90 OR 91 OR 92 OR 93 OR 94 OR 95 OR 96 OR 97 OR 98 OR 99 OR 100
102. "water-based"
103. "aqua-based"
104. "aquatic-based"
105. "water"
106. "aqua"
107. "aquatic"
108. "aquatics"
109. 102 OR 103 OR 104 OR 105 OR 106 OR 107 OR 108
110. "exercising"
111. "exercise"
112. "exercises"
113. "motor activity"
114. "motor activities"
115. "physical activity"
116. "physical activities"
117. "sport"

118. "sports"
119. "sporting"
120. "Exercise"[Mesh]
121. "Motor Activity"[Mesh]
122. "Sports"[Mesh]
123. 110 OR 111 OR 112 OR 113 OR 114 OR 115 OR 116 OR 117 OR 118 OR 119 OR 120 OR 121 OR 122
124. 109 AND 123
125. 101 OR 124
126. "bone"
127. "bones"
128. "fracture"
129. "fractures"
130. "osteoporosis"
131. "osteoporoses"
132. "osteopenia"
133. "osteopaenia"
134. "Bone and Bones"[Mesh]
135. "Fractures, Bone"[Mesh]
136. "Bone Density"[Mesh]
137. "Osteoporosis"[Mesh]
138. 126 OR 127 OR 128 OR 129 OR 130 OR 131 OR 132 OR 133 OR 134 OR 135 OR 136 OR 137
139. 125 AND 138

Appendix III: Characteristics of included studies (Chapter 3)

Study ID	Design	Duration	Number of participants	Losses	Participants	Age	Water-based exercise	Comparison groups	BMD measurement	Secondary outcomes	Medications/ supplements	Adverse events	Compliance/ Adherence
Borba-Pinheiro 2010	QE	12 mts	35	NR	- Sex: females - Characteristics: women with osteoporosis/ osteopenia, being treated with alendronate, no previous history of fractures and no history for at least 1 year of regular practice of PA, in good physical and mental health	45.6 to 64.5 years	- Exercise: hydrogymnastics - Frequency: 3x/week, 60 minutes, 6 bimonthly cycle - Intensity: Borg scale, 12 during the first 2 months and between 14-16 during the rest of the study - Setting: 12-m section of a 25-m pool	- RTG - JUG - CG	- Equipment: DEXA Lunar DPX - Variables: BMD (g/cm²) - Regions: lumbar spine (L2-L4), neck of the femur, greater trochanter and Ward's triangle	- Body balance - Quality of life	Alendronate sodium 70mg/week	NR	NR
Borba-Pinheiro 2012	QE	12 mts	84	NR	- Sex: females - Characteristics: volunteers with osteoporosis and/or osteopenia in at least one of the DXA measures, undergoing treatment with alendronate sodium (70 mg/week) and/or vitamin D, and no history of fractures, in good physical and mental health	49 to 61.8 years	- Exercises: hydrogymnastics - Frequency: three 60-min sessions per week on alternate days - Intensity: Borg scale, 11-12 during the first two months and between 13-16 during the rest of the study - Setting: 12-m section of a 25-m pool	- CG	- Equipment: DEXA Lunar DPX - Variables: BMD (g/cm2) - Regions: lumbar spine (L2–L4), femoral neck and greater trochanter	- Quality of life	Alendronate sodium 70mg/week and/or Vitamin D3 5600 IU/week	NR	NR
Kemper 2009	RCT	6 mts	30	7 (2 SWM / 5 RTG)	- Sex: females - Characteristics: sedentary	63.9 ± 6.49 years	- Exercises: swimming - Frequency: 3 days/week, one hour per session	- RTG	- Equipment: DEXA Lunar DPX-IQ - Variables: BMD (g/cm2)	- Body composition	-	NR	>75% of sessions

					postmenopausal women	(mean ± SD)	- Intensity: sessions began with moderate intensity activities (60% heart rate reserve) and reached high intensity activities (90% heart rate reserve) - Setting: pool with 1.50m depth, and the water temperature during sessions remained between 27 and 29ºC		- Regions: lumbar spine (L2-L3-L4) and femoral neck				
Moreira 2014	RCT	6 mts	108	8 (5 AEG / 3 CG)	- Sex: females - Characteristics: physical activity status classified as sedentary by the IPAQ short version questionnaire, post-menopausal for at least 5 years and cognition function allowed to understand and respond to the authors' questions and commands during the questionnaires, no physical conditions that might affect performance during aquatic exercises; no chronic kidney disease; no history of recent hip fracture (in the last 2 years); no dependency on alcohol or illicit drugs; no chronic therapy with corticosteroids, bisphosphonates, calcitonin, calcium, vitamin D and its metabolites; no use of estrogen, selective estrogen receptor modulators and strontium in the	58.8 ± 6.4 years (mean ± SD)	- Exercises: hydrogymnastics - Frequency: 3 times/week, sessions lasted from 50 to 60 min - Intensity: level 6 in Borg Scale (approx. 60% of MHR) during 16 min of the session in weeks 5–9, level 7 in Borg Scale (approx. 70 % of MHR) during 13 min of the session in weeks 10–14, level 8 in Borg Scale (approx. 80 % of MHR) during 9 min of the session in weeks 15–19, and level 9 in Borg Scale (approx. 90 % of MHR), during 7 min of the session in weeks 20–24 - Setting: covered swimming pool, with depth varying between 1.10 and 1.30 m and water temperature between 30 and 31ºC	- CG	- Equipment: DEXA Hologic QDR - Variables: BMD (g/cm^2) - Regions: lumbar spine (L1-L4), femoral neck, total femur, total body	- Biomarkers of bone turnover (iPTH, P1NP, CTx)	Daily suppl. of 500 mg of elementary calcium and 1,000 IU of vitamin D (cholecalciferol), combined in the same pill	NR	92.6% (95% CI, 85-98%

					earlier 6 months; no use of any medications that might interfere with vitamin D metabolism; systolic blood pressure <200 mmHg and/or diastolic blood pressure <100 mmHg								
Murtezani 2014	RCT	10 mts	64	3 (2 LE / 1 AE)	- Sex: females - Characteristics: women recently diagnosed (within the past 6 months) with osteoporosis on account of a DEXA scan T score below -2.5, aged 50-70 years, who had no history of vertebral fractures or lower extremity fractures, did not have endoprostheses or fixation materials and were capable of signing written informed consent	50 to 70 years	- Exercises: hydrogymnastics - Frequency: 3 times/week, 35 min - Intensity: Participants were instructed to exercise at an intensity that was moderate to hard (12-14 on the 20-point Borg perceived exertion scale) - Setting: not stated (only reported that water temperature was 30)	- LE	- Equipment: DEXA GE Lunar Prodigy - Variables: BMD (g/cm²) - Regions: lumbar spine (L2-L4)	- Muscle strength - Flexibility - Balance - Gait time - Pain	Ca (1000 mg daily) and Vitamin D (800-1000 IU daily)	NR	NR
Novaes 2013	QE	6 mts	31	NR	- Sex: females - Characteristics: living independently in the community, aged 55 or above, postmenopausal status, being without contraindications to physical activity and not reporting history of regular structured exercise	66.9 ± 6.1 years (mean ± SD)	- Exercises: hydrogymnastics - Frequency: 3 times/week, sessions lasting 45 min - Intensity: participants were instructed to attain 70 to 80% of their work heart rate - Setting: public indoor swimming pool with a water depth of 1.20-1.40 m and a water temperature of 30.5 °C	- ST	- Equipment: DEXA Hologic - Variables: BMD (g/cm²) - Regions: left femoral neck and lumbar spine (L1-L4)	-	-	-	>85%

Pernambuco 2013	RCT	8 mts	84	17 (6 AEG / 11 CG)	Sex: females Characteristics: aged 60 years or older, with low BMD and no neurological disorders who did not exercised regularly for a minimum of six months prior to the study and did not suffered from metabolic or endocrine disorders	60 to 77 years	- Exercises: hydrogymnastics - Frequency: twice weekly, 50 min - Intensity: not reported - Setting: swimming pool 25m long and 1.40m deep	- CG	- Equipment: DEXA Lunar DPX-L - Variables: BMD (g/cm²) - Regions: lumbar spine (L2–L4) and right total femur	- Bone formation (serum osteocalcin) - Functional autonomy	Volunteers with osteoporosis took alendronate sodium (70 mg) once a week and vitamin D3 once a day, while those with osteopenia used only vitamin D3	NR	NR
Rotstein 2008	QE	7 mts	35	5 (all from intervention group)	Sex: females Characteristics: non-smokers, did not suffer from thyroid gland problems or hypertension, and did not suffer from osteoporosis (baseline bone density was higher than 55% of the mean bone density for the normal population of the subject's age), not taking any of the following medications: B complex, Betaxolol ophthalmic suspension, anastrozole, brotizolam, glucosamine, chondroitin, ofloxacin, atenolol, cilazapril, estradiol, norethisterone, pravastatin, losartan,	50 to 65 years	- Exercise: hydrogymnastics - Frequency: three one-hour sessions per week - Intensity: 12- 16 on Borg scale - Setting: pool, water temperature was 32 °C, and all activities were conducted with the water at chest level	- CG	- Equipment: DEXA Lunar - Variables: BMD (g/cm2) and BMC (g) - Regions: lumbar spine (L2-L4) and femoral neck	-	-	NR	NR

					amlodipine and Aspirin								
Tsukahara 1994	QE	12 mts	97	32 (7 from veterans group and 25 from newcomers group)	- Sex: females - Characteristics: healthy postmenopausal women	59.75 to 65.08 years	- Exercise: hydrogymnastics and swimming - Frequency: 1x/week, 45 min/ session - Intensity: level of activity had two Maximum Working Heart Rate peaks (approximately 120beats/min) - Setting: sports club, warm water (28-29ºC)	- Newcomers - CG	- Equipment: DEXA Hologic QDR - Variables: BMD (g/cm²) - Regions: lumbar spine (L1-L4)	-	-	NR	NR
Vanaky 2014	RCT	3 mts	20	NR	- Sex: females - Characteristics: none smoker females aged between 50 and 70 years; postmenopausal for at least 12 months; not institutionalized; and having no contraindication to undertaking physical exercises without close medical supervision, hormone therapy and calcium consumption and without cardiovascular and thyroid history	50 to 70 years	- Exercise: hydrogymnastics - Frequency: 3 times/week, 1h15min/session (after the second week) - Intensity: the intensity of the jumps was adjusted to approximately 60% of the heart rate reserve (HRR). During the second week, the intensity was increased to 80% of the HRR - Setting: pool	- CG	- Equipment: DEXA - Variables: BMD - Regions: lumbar spine (L2 to L4) and femoral neck	- Functional fitness	-	NR	NR
Wu 2000	QE	24 mts	41		- Sex: females - Characteristics: postmenopausal	SWM - 59.5 ± 6.1 years CG - 59.3 ± 5.2	- Exercise: swimming - Frequency: 1.5 times/week, 1h/session - Intensity: NR - Setting: pool	- CG	- Equipment: DEXA Norland - Variables: BMD (g/cm²) - Regions: lumbar spine (L1 to L4) and proximal femur	- Leg extension power	-	-	-

Abbreviations: QE = quasi-experiment / RCT = randomized controlled trial / mts = months / NR = not reported / RTG = resistance training group / JUG = judo group / CG = control group / SWM = swimming group / AEG = aquatic exercises group / LE = land exercise group / ST = strength training group / BMD = bone mineral density / BMC = bone mineral content / SD = standard deviation / CI = confidence interval

Appendix IV: Dual energy X-ray absorptiometry positioning protocols in assessing body composition: A systematic review of the literature – published version

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Review

Dual energy X-ray absorptiometry positioning protocols in assessing body composition: A systematic review of the literature

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ABSTRACT

Objectives: To systematically identify and assess methods and protocols used to reduce technical and biological errors in published studies that have investigated reliability of dual energy X-ray absorptiometry (DXA) for assessing body composition.

Design: Systematic review.

Methods: Systematic searches of five databases were used to identify studies of DXA reliability. Two independent reviewers used a modified critical appraisal tool to assess their methodological quality. Data was extracted and synthesised using a level of evidence approach. Further analysis was then undertaken of methods used to decrease DXA errors (technical and biological) and so enhance DXA reliability.

Results: Twelve studies met eligibility criteria. Four of the articles were deemed high quality. Quality articles considered biological and technical errors when preparing participants for DXA scanning. The Nana positioning protocol was assessed to have a strong level of evidence. The studies providing this evidence indicated very high test–retest reliability (ICC 0.90–1.00 or less than 1% change in mean) of the Nana positioning protocol. The National Health and Nutrition Examination Survey (NHANES) positioning protocol was deemed to have a moderate level of evidence due to lack of high quality studies. However, the available studies found the NHANES positioning protocol had very high test–retest reliability. Evidence is limited and reported reliability has varied in papers where no specific positioning protocol was used or reported.

Conclusions: Due to the strong level of evidence of excellent test–retest reliability that supports use of the Nana positioning protocol, it is recommended as the first choice for clinicians when using DXA to assess body composition.

1. Introduction

Dual-energy X-ray absorptiometry (DXA) is a widely accepted method for the assessment of tissue composition.[1] Low bone mineral density (BMD) and associated conditions such as osteoporosis and osteopenia constitute a significant health problem that costs over eight hundred and thirty million dollars annually and osteoporosis is a significant cause of morbidity and mortality.[2,3] The need to accurately and effectively measure BMD in conditions such as osteoporosis led to the development of the DXA scanner.[4] Now, DXA is considered the gold standard for the assessment of BMD and associated fracture risk.[5] However, DXA is also a valuable clinical tool in the assessment of body composition (BC), due particularly to its ability to assess body segments for lean mass (LM) and fat mass (FM) distributions.[6] The absorption rates of the two different energy levels (40 and 70 KeV) within DXA coupled with the distinctive elements of bone, fat, and lean tissue enable clear imaging of each tissue type and subsequent analysis.[6] Therefore, DXA can be used for assessing segmental body composition (SBC) and is currently used in clinical, sporting and research settings. The data gathered from SBC scans have improved knowledge of malnutrition, growth, aging, obesity and the efficacy of medical treatment interventions (surgical, pharmacological, dietary and exercise).[7] When used in the sport setting, DXA has enabled the tracking of players overall tissue composition as it has been found that individuals with the lowest start of season BMD and LM values have a greater occurrence of bone related injuries.[8] Nevertheless, the

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reliability of the DXA scanner is fundamental to the validity of all clinical investigations and research studies that use it to assess BC.

In order to draw valid and reliable conclusions from DXA scan results, the concept of error must be considered. The literature describes biological and technical error as sources for reduced test–retest reliability of the DXA scanner.[9] The International Society for Clinical Densitometry recommends precise measures during preparation of the participant (fasting state, clothing, time of day, physical activity and empty bladder) and consistent positioning.[9] It has been shown that sources of biological error in DXA results include hydration,[1,9,10] stomach content and food consumption,[1,9,10] time of day of scanning[9] and physical activity[9,10]; furthermore sources of technical error include artefacts such as clothing,[9] number of operators used to complete scans[11] and position of participant.[1,9,12,13]

The influence of positioning of the participant on the DXA scanner can be analysed further by considering three identifiable positioning protocols. The first of these is the National Centre for Health Statistics, National Health and Nutrition Examination Survey (NHANES) Body Composition[12] positioning protocol, which the International Society for Clinical Densitometry recommends.[9] The NHANES protocol requires individuals to assume a supine position with feet secured together with a strap, and the palms of the hands flat on the scanning table and not touching the lateral aspect of the body. It should be noted that the Australian and New Zealand Bone Mineral Society (ANZBMS)[14] employs the same body position. The second key protocol, the Nana positioning protocol,[1] requires individuals to be in a supine position while placing hands in a neutral position alongside the body and feet in radio-opaque positioning pads. The third approach evident in the literature involves no specific positioning protocol being reported at all.

The study of Kerr et al.[13] is to date the only study that has attempted to compare the reliability of different DXA positioning protocols for assessing BC, to identify which protocol was the most valid and reliable to use in clinical practice. They reported the Nana positioning protocol was the preferred positioning protocol based upon participant comfort when assessing BC with DXA. In their study, the positioning protocols were modified versions of the standard Nana and NHANES protocols. In contrast, most other studies that have assessed the test–retest reliability of their DXA scanner have not compared the reliability of different positioning protocols.

Therefore, the aim of this literature review was to systematically identify and assess methods and protocols used in previously published research that has investigated reliability of DXA, when it is employed to assess BC, to reduce technical and biological errors.

2. Methods

A search of academic databases was undertaken on 26.09.2016 with the intention of finding studies that have assessed the test–retest reliability of positioning protocols used when assessing BC by DXA. The search was limited to studies conducted over the recent 10-year period (01.09.2006–26.09.2016) to maintain currency. The search was limited to only articles that included the term 'DXA' or a synonym for DXA in the title, as searches not limited in this way provided an excessive number of irrelevant articles. Details of the search strategy and key terms can be found in Fig. 1.

Two reviewers (F.S and C.P) assessed the identified literature and removed duplicates. Titles and abstracts were initially screened and articles removed if eligibility criteria were not met. Inclusion criteria included: (1) studies conducted on living human participants, (2) studies of an adult population, and (3) studies primarily investigating reliability of DXA scanning protocols. Exclusion criteria were: (1) non-healthy subjects (e.g. subjects with: osteoporosis, current fractures, hemiarthroplasty and total joint replacements, rheumatoid or osteoarthritis, current cardiac or pulmonary conditions, or diabetes) (2) studies published prior to September 2006, (3) studies comparing MRI or CT to DXA, and (4) studies not available in English. In the event that insufficient details were provided in the titles and abstracts of articles to allow determination of eligibility, review of full texts was completed, with reference to eligibility criteria and ineligible articles were removed. The remaining articles were included in this literature review. A PRISMA flow diagram (Fig. 1) was used to document the study screening and article selection processes.[15]

In order to critically appraise the included DXA reliability full text articles, a modified version of the reliability and validity critical appraisal tool (CAT) described by Brink and Louw[16] was utilised, with items designed to appraise studies of validity removed, since the focus of this review was studies of reliability. The thirteen-item CAT was reduced to ten items by removing all items that did not relate to reliability, and was applied by two independent reviewers (F.S and C.P) in order to assess the methodological quality of each study. When both assessors were not in agreement, a consensus was reached by discussion to determine the item's final CAT results. The CAT did not originally include a scoring system; therefore for the purpose of this literature review, a scoring system was implemented to aid in a quality and reliable analysis, similar to previously published reviews.[17–20] Studies of higher quality scored ≥60% in the modified CAT, and were rated higher due to their superior methodology.[21]

To receive a positive appraisal regarding the appropriateness of statistics in the CAT, each study reporting reliability must have reported an intraclass correlation coefficient (ICC) accompanied with confidence intervals (CI) or a percentage change in mean accompanied with typical error of measurement.[22] If the only basis for inclusion of a study was that it reported a percentage change in mean, then the calculation of the percentage change in mean must have complied with the guidance of previous work and have included a typical error of measurement in calculations.[23,24] Pearson correlation coefficients were not deemed suitable as measures of reliability; as they did not take into account the consistency of measurements from test to retest and the change in average measurements of participants.[25] The ICC results of the studies that included ICC values were interpreted as indicators of reliability as follows: ICC of 0.00–0.29, very low reliability; 0.30–0.49, low reliability; 0.50–0.69, moderate reliability; 0.70–0.89, high reliability; and 0.90–1.00, very high reliability.[26] An assessment of high or very high reliability depended primarily upon a reported high or very high ICC (above 0.70) or a low reported percentage change in the mean. When used the reported change in mean needed to be lower than the minimum clinically significant difference ascertained through consultation with practitioners. This ensured that any systematic error in repeated measurements observed during reliability testing was not sufficiently large to obscure clinically important changes or differences in the respective outcome measure — another indication of reliability. Unfortunately, only three studies in this review reported minimum clinically significant differences and therefore this statistic could not be used to compare studies.

Following critical appraisal, data were extracted from the included full text articles and tabulated to identify participant characteristics, the extent of standardisation employed to minimise technical and biological errors, the types of statistical analyses undertaken, and reported results of each study.

A meta-analysis was not undertaken due to the diversity of the methods examined and the statistical analyses employed. Rather, a critical narrative approach was applied to synthesise and analyse the data obtained from the included studies, using a level of evidence approach.[27] Each positioning protocol identified from included studies was assigned a 'strong', 'moderate', or 'limited'

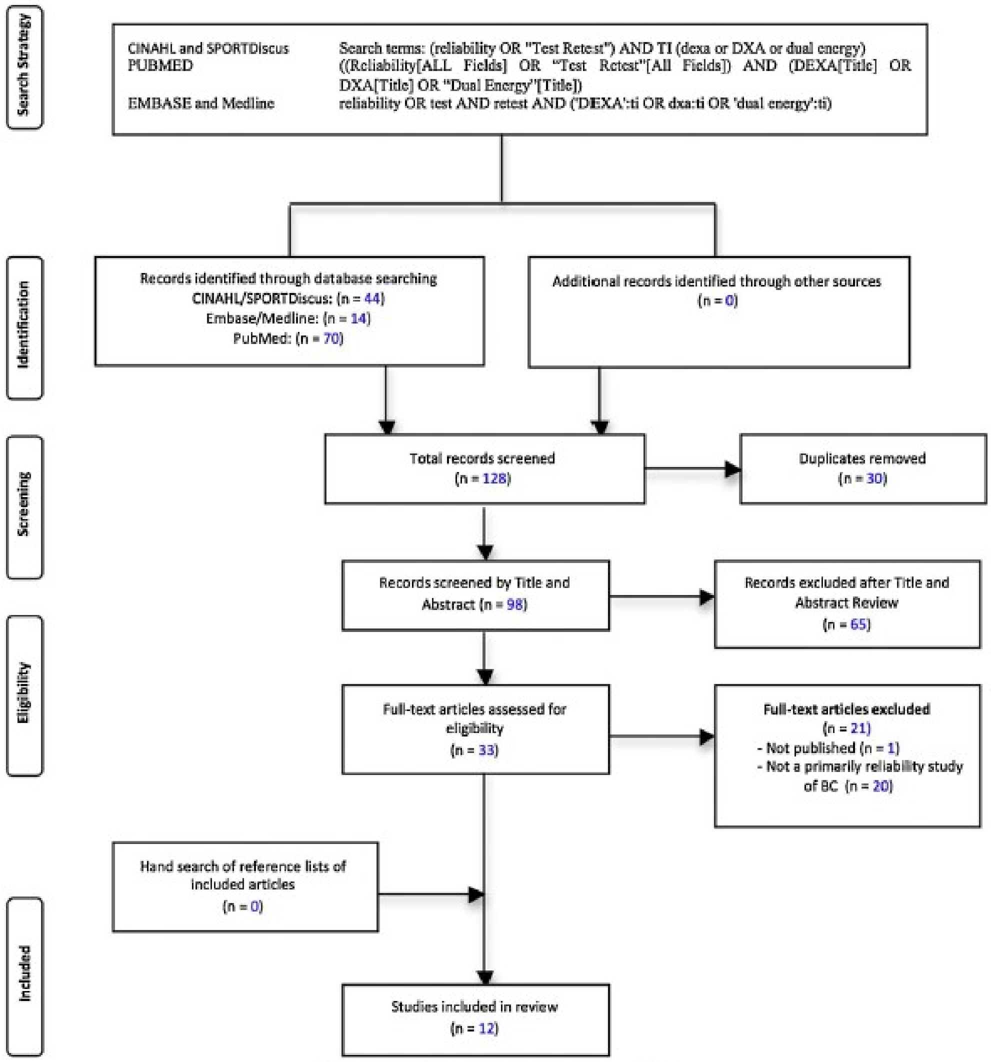

Fig. 1. PRISMA flow diagram of literature search strategy.

level of evidence, based upon the number of studies that had examined its reliability and the quality of these studies. In order to be rated as having a strong level of evidence, a protocol required consistent findings from ≥3 high quality studies; to be assessed as having a moderate level of evidence, a protocol required consistent findings from at least 1 high quality study and 1 or more low quality studies; and to be assessed as having a limited level evidence, a protocol required consistent findings from ≥1 low quality study or only having 1 study available.

The use of standardisation of methods of measurement to control sources of biological and technical error was assessed based upon the recommendations from the International Society of Clinical Densitometry.[9] Studies that reported having used the appropriate controls were considered more robust. As such the study must have included descriptions indicating how technical (clothing, positioning protocol) and biological (hydration, fasting state, time of day of scanning and physical activity) sources of error were controlled.

3. Results

The results of the electronic database literature search and subsequent screening and selection process are depicted in Fig. 1. The search yielded 128 results. After titles and abstracts were screened and clearly-ineligible studies and duplicates removed,[15] the full texts of 33 articles were obtained and further assessed based upon the inclusion/exclusion criteria. Twelve articles were subsequently included in this review.

A total of 724 participants were involved in the twelve (12) studies included in this review. Three hundred and eight (308) were males; two hundred and sixty seven (267) were females; and two studies[28,29] involved one hundred and forty nine (149) participants but did not categorise participants' based on gender. The reported range of participant mean ages was 22.7–71.5 years, with the mean being 39.4 years. Nine studies reported mean mass, with the range of mean masses being 68.0–98.1 kg and the mean being 77.1 kg; similarly, the range of reported heights was 168.0–186.0 cm, with the mean being 174.8 cm. Three[30–32] studies reported BMI instead of reporting mass and height and in those studies BMI ranged from 26.5 to 27.1 kg/m^2, with the mean being 26.8 kg/m^2.

Of the twelve included studies, only four of the studies were assessed as high quality using the CAT. Nine[1,10,13,28,30,31,33–35] of the twelve studies reported statistics that were deemed appropriate (percentage change in mean accompanied by typical error or ICC). The three studies[29,32,36] that failed to report appropriate statistics were deemed to be of insufficient quality to warrant a high rating from the CAT[21]. Seven[1,10,13,28,32–34] of the twelve included studies used methods that were assessed as being reproducible, but only four[1,10,13,33] of these were rated as high quality studies. A detailed description of all articles assessed using the CAT can be found in Table 1.

The extent of standardisation of procedures to limit biological and technical errors varied significantly between the studies. Only three[1,10,13] of the twelve included studies reported all of the desirable information on the following standardised procedures: positioning protocol, clothing worn, physical activity completed by participant on day of scan, participant food intake on day of scan, participant hydration status and the time of day that the scanning took place. A further eight studies[1,10,13,28,29,33–35] reported if clothing was worn, whilst seven studies[1,10,13,33–36] checked hydration status and six studies[1,10,13,28,35,36] reported scanning participants in a fasted state. Less than half of the studies[10,13,28,35] reported scanning participants in a rested state. The time of the scan was only reported in four[1,10,13,28] of the twelve studies.

The 12 included studies reported a variety of statistical representations of reliability, including percentage change in mean with the typical error of measurement, or ICC with CV. Of the studies that reported ICC, all found the DXA results to have very high test–retest reliability[26]. All studies that used a percentage change in mean as the test–retest reliability measure reported a change of less than one percent, and all percentage changes in mean were less than the minimum clinically significant difference. A summary of the reliability results from the included studies can be found in Table 2.

When applying a level of evidence approach, it was found that the Nana protocol had a strong level of evidence regarding DXA test–retest reliability, based on high quality articles as assessed by the CAT (Table 1), whilst the NHANES positioning protocol was deemed to have only a moderate level of evidence regarding reliability. This was due to only two high quality studies being reported in the literature for the NHANES positioning protocol, when available studies were assessed using the CAT (Table 1). Where no positioning protocol was reported in a study or a positioning protocol was not detailed, the level of evidence was deemed to be limited.

4. Discussion

This literature review included twelve studies of test–retest reliability of DXA measurements when used to assess BC in healthy cohorts. The findings of these studies can assist in determining what factors need to be accounted for when using DXA scans to assess individuals for BC, to achieve high test–retest reliability in DXA results. Studies that accounted for both sources of technical error (scanner qualifications, reduction of chance of artefacts effecting results, the positioning protocol followed) and sources of biological error (hydration, stomach content and food consumption, time of day of scanning and effects of physical activity) were found to have superior methodologies and reported greater DXA test–retest reliability.

Additionally, this review examined which DXA positioning protocol for assessment of BC (Nana, NHANES, no specified protocol or no protocol) had the highest level of evidence regarding test–retest reliability. It was evident that the Nana positioning protocol had the highest level of evidence regarding test–retest reliability of associated DXA results and this protocol was also deemed the most reliable protocol when conducting DXA scans for this purpose.

The Nana positioning protocol requires the use of pads, which are transparent under DXA, to minimise movement as well as increase reproducibility. Assessment of the studies of Nana et al.,[1,10] and Kerr et al.[13] indicated the Nana positioning protocol was the most reliable based upon three considerations. Firstly, the critical appraisal of the methodological quality of these studies indicated they were high quality studies; secondly, the reliability results reported in these studies indicated high test–retest reliability of the DXA results; and lastly, the methodological provisions employed in these studies to minimise biological and technical errors were robust. The results of this review therefore support the findings of Kerr et al.[13] that the Nana positioning protocol produces quality and reliable results; and also reinforces the original work of Nana et al.[1] in the development of a superior positioning protocol.

The reliability of the NHANES positioning protocol in assessing BC has only been assessed in two studies[13,33] and therefore can only be judged from a moderate level of evidence. The NHANES positioning protocol requires the participant to assume a supine position, with palms flat on the table and a strap securing the lower limbs to minimise movement.[12] According to our CAT assessment, the overall methodological quality of these articles was high. The statistical results and methodological provisions to minimise technical and biological errors also appear to be sound. However, it is important to note that one of the included studies[33] lacks provision for the participant to be rested and standardisation of time of scanning. Ultimately, more high quality research is required for the NHANES positioning protocol before it could be recommended, based upon the criteria used in this review.

The level of evidence is limited from studies[28,30–32,34] which have not followed a specific positioning protocol such as the Nana or NHANES protocol. This is a result of low methodological quality of these studies. The results not surprisingly indicate lower reliability of DXA results when using such poorly-defined protocols. Additionally, all of the studies of this type did not include methodological provisions to standardise the participants to limit biological and technical errors.

A limited level of evidence was also yielded by studies[29,35,36] that did not include a description of the positioning of the participants in the methods. This omission resulted in poor CAT scores and was associated with fluctuations in reported DXA results and the omission of methodological provisions to overcome sources of biological and technical errors.

Therefore, when scanning individuals using DXA to assess BC it is advised that clinicians use a positioning protocol such as the Nana[1] or NHANES[12] protocols to minimise technical errors and that they ensure the technician performing the scans is qualified. Additionally, accounting for biological sources of error (hydration, stomach content and food consumption, time of day of scanning and effects of physical activity) is vitally important when using the afore mentioned positioning protocols. Of these two

Table 1
Critical appraisal tool.

Article	Subjects	Characteristics	Scanner qualified	Rater		Random order	Test retest		Can reproduce protocol	Withdrawals explained	Statistics reported appropriate	High quality?
				Intra	Inter		Time period	Period valid				
Bilsborough et al.[33]	47 47M	Yes 22.7 ± 3.0 years 84.4 ± 5.62 kg, 186 ± 5 cm	Yes	NA	No	Yes	Yes Immediate	Yes	Yes	No	Yes ICC %CV	Yes
Colyer et al.[34]	53 34M 19F	Yes 23.0 ± 4.0 years 79.9 ± 18.9 kg, 178 ± 10 cm	No	No	No	No	Yes 2 days	Yes	Yes	No	Yes ICC %CL	No
Covey et al.[30]	42 1M 41F	Yes 50.4 ± 9.9 years 27.1 ± 6.1 kg/m^2	Yes	NA	No	No	Yes 1 day	Yes	No	No	Yes % Difference Limit of agreement	No
Covey et al.[31]	39 39F	Yes 56.6 ± 9.6 years 26.8 ± 5.5 kg/m^2	Yes	NA	No	No	Yes 7–14 days	Yes	No	No	Yes % Difference Limit of agreement	No
Hurst et al.[35]	166 81M 85F	Yes 38.9 (36.9–40.9) years 75.5 kg, 171 cm	No	NA	No	No	Yes Max 5 days	Yes	No	No	Yes % Change	No
Kerr et al.[13]	30 14M 16F	Yes 36 ± 11.5 years 71.0 ± 7.1 kg, 173.5 ± 0.5 cm	Yes	NA	No	Yes	Yes Immediate	Yes	Yes	No	Yes % Change %CV	Yes
Lohman et al.[32]	30 30M	Yes 45.2 (22.0–61.0) years 26.5 (17.8–33.9) kg/m^2	Yes	NA	No	No	Yes Immediate	Yes	Yes	No	No Pearson r value	No
Moon et al.[36]	82 44M 38F	Yes 71.5 ± 5.3 years 71.4 ± 8.1 kg, 168.3 ± 5.3 cm	No	NA	No	Yes	Yes 12 Weeks	No	No	No	No Pearson r value	No
Nana et al.[1]	31 16M 15F	Yes 27.0 ± 5.0 years 68 ± 7.5 kg, 172.5 ± 6.0 cm	Yes	NA	No	No	Yes Immediate	Yes	Yes	No	Yes % Change %CV	Yes
Nana et al.[10]	55 41M 14F	Yes 27.7 ± 6.3 years 75.5 ± 7.9 kg, 176.4 ± 5.7 cm	Yes	NA	No	No	Yes Immediate	Yes	Yes	No	Yes % Change %CV	Yes
Smith-Ryan et al.[28]	127	Yes 35.8 ± 9.4 years 98.1 ± 20.9 kg, 176.3 ± 9.2 cm	No	NA	No	No	Yes 7–10 days	Yes	Yes	No	Yes ICC %CV	No
Wilson et al.[29]	22	Yes 37.8 ± 15.5 years 70.1 ± 14.8 kg, 172.0 ± 11.4 cm	Yes	NA	No	No	No	Yes	No	No	No Root square mean %CV	No

M: male, F: female, cm: centimetres, kg: kilograms, kg/m^2 kilograms per square metre, % Change: percentage change in mean, ICC: intraclass correlation coefficient, %CV: percentage of coefficient of variation, CL%: confidence limit percentage, SEE: standard error estimation.

Table 2
Overview of results of studies of test–retest reliability of DXA measurements of BC.

Authors	Variable/condition	Intrarater reliability between scans						High quality
		ICC or % change in mean* or % difference** or Pearson correlation #			CV% (TEM or SEM) or CL%* or limit of agreement #			
		BMC	LM	FM	BMC	LM	FM	
Bilsborough et al.[31]	Lunar – fan beam	1.00	1.00	0.99	0.60	0.30	2.50	Yes
Bilsborough et al.[31]	Lunar – pencil beam	1.00	1.00	0.98	1.50	0.50	5.90	Yes
Colyer et al.[32]	–	–	1.00	0.99	–	1.2*	1.2*	Yes
Covey et al.[28]	Discovery Wi machine ##	0.34**	−0.07**	0.29**	−0.04 to 0.06#	−1.10 to 1.10#	−0.70 to 0.77#	No
Covey et al.[28]	QDR machine ##	−0.40**	0.14**	−0.01**	−0.09 to 0.07#	−1.39 to 1.51#	−0.87 to 0.95#	No
Covey et al.[29]	QDR machine ##	−0.50**	0.30**	0.00**	−0.05 to 0.05#	−1.16 to 1.27#	−0.67 to 0.65#	No
Covey et al.[29]	Discovery Wi machine ##	0.20**	−0.10**	0.60**	−0.03 to 0.03#	−0.81 to 0.83#	−0.81 to 0.83#	No
Hurst et al.[33]	–	–	–	0.01*	–	–	–	No
Kerr et al.[11]	NHANES protocol	0.10*	−0.10*	0.20*	0.90	0.80	2.60	Yes
Kerr et al.[11]	NANA protocol	−0.40*	0.20*	−0.20*	1.00	0.60	2.20	Yes
Lohman et al.[30]	–	0.99#	0.99#	1.00#	–	–	–	No#
Moon et al.[34]	–	–	0.87 F 0.95M#	–	–	–	–	No#
Nana et al.[1]	Immediate retest	−0.10F 0.30M*	0.20F 0.00M*	0.00F −0.40M*	1.00F 0.70M	0.50F 0.40M	1.30F 1.90M	Yes
Nana et al.[1]	Retest 24 h later	−0.30F −0.20M*	0.00F −0.20M*	−0.40F −0.60M*	1.10F 0.70M	1.00F 0.50M	1.30F 2.10M	Yes
Nana et al.[8]	Strength group	0.00*	0.00*	0.10*	1.00	0.60	2.50	Yes
Nana et al.[8]	Cycling group	−0.10F 1.90M*	0.30F 0.00M*	−0.10F −0.10M*	0.80F 5.20M	0.80F 1.50M	1.90F 1.40M	Yes
Smith-Ryan et al.[26]	–	–	0.996	0.995	–	0.83	0.99	Yes
Wilson et al.[27]	–	0.85 total mass			1.08 total mass			No

BMC: bone mineral content, LM: lean mass, FM: fat mass, ICC: intraclass correlation coefficient, CV%: percentage of coefficient of variation, CL%: confidence limit percentage, ?: root square mean error, ##: regional assessment of trunk only, CV% TEM (typical error of measurement) or SEM (standard error of measurement) percentage, F: female, M: male.

protocols, the Nana protocol currently has the highest level of evidence indicating that it should be the preference for clinicians.

Interestingly, Kerr et al.[13] also included a measure of comfort of participants. In this study, they used a modified version of the Nana positioning protocol (adding straps around the waist to secure the arms and the distal lower limb to "minimise any subject movement") and a modified version of the NHANES positioning protocol (in which the participants hands were placed against the body but not secured). It could be postulated that these changes to the original positioning protocols may have favoured the Nana positioning protocol, as subjects in the NHANES protocol had to actively hold their arms in a static position during the DXA scan. Perhaps not surprisingly, then, the Nana protocol was favoured by participants based on comfort.

Limitations of this literature review include the non-inclusion of grey literature, and the focus of the literature review being only test–retest reliability. This latter focus may have excluded some studies which did not report test–retest reliability in their abstracts. The removal of non-English studies and the exclusion criterion of non-healthy subjects may have also reduced the number of included studies in this review. Additionally, this review only focused on whole body BC scans and did not consider hemiscans or compilations of partial scans, as there is a scarcity of studies that have investigated this technique.

Strengths of this literature review include the systematic approach employed and the rigorous methodology followed, using the PRISMA statement[15] as a guide. Additionally, the utilisation of the modified CAT tool and independent reviewers aided and upheld high quality assessments of methodological quality. Furthermore, this is the only literature review to assess multiple variables in the methodology that affect the reliability of DXA measurements of SBC.

This literature review has affirmed the need for more high quality research to assess the test–retest reliability of DXA measurements of BC using the NHANES positioning protocol. Clinicians would benefit from research that more robustly compares the Nana and the NHANES positioning protocols. Robust further research would serve to elevate the NHANES positioning protocol to a similar level of evidence as the Nana positioning protocol.

5. Conclusion

This review aimed to assess the different protocols and methodological approaches used to reduce technical and biological errors in previously published studies that have investigated test–retest reliability of DXA when used to assess BC. The results of this literature review can usefully guide for future clinicians using DXA to assess BC in a variety of settings including elite sport, community health and research. As such, this review indicates that the Nana positioning protocol, when coupled with methodological provisions to minimise biological and technical sources of error, is the positioning protocol with the strongest level of evidence and high levels of test–retest reliability, and thus should be the choice of clinicians when using DXA to assess BC. Currently, moderate level evidence of high test–retest reliability exists for the NHANES positioning protocol and more high quality research using this protocol is required to enhance the level of available evidence. Not using a positioning protocol or not reporting the protocol employed means studies of DXA reliability are then of low methodological quality; too low to enable recommendations to be made based on their findings.

Practical implications

Methodological provisions to reduce technical errors and biological errors is of paramount importance to produce reliable DXA measurements of BC.

The use of positioning protocols in such DXA scanning increases the reliability of results.

To minimise technical error, the Nana positioning protocol should be the first choice for clinicians when assessing BC.

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Appendix V: Investigating the level of agreement of two positioning protocols when using Dual Energy X-Ray Absorptiometry (DXA) in the assessment of Body Composition (BC) – published version

Investigating the level of agreement of two positioning protocols when using dual energy X-ray absorptiometry in the assessment of body composition

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ABSTRACT

Background. Dual energy X-ray absorptiometry (DXA) is a commonly used instrument for analysing segmental body composition (BC). The information from the scan guides the clinician in the treatment of conditions such as obesity and can be used to monitor recovery of lean mass following injury. Two commonly used DXA positioning protocols have been identified—the Nana positioning protocol and the National Health and Nutrition Examination Survey (NHANES). Both protocols have been shown to be reliable. However, only one study has assessed the level of agreement between the protocols and ascertained the participants' preference of protocol based upon comfort. Given the paucity of research in the field and the growing use of DXA in both healthy and pathological populations further research determining the most appropriate positioning protocol is warranted. Therefore, the aims of this study were to assess the level of agreement between results from the NHANES protocol and Nana protocol, and the participants' preference of protocol based on comfort.

Methods. Thirty healthy participants (15 males, 15 females, aged 23–59 years) volunteered to participate in this study. These participants underwent two whole body DXA scans in a single morning (Nana positioning protocol and NHANES positioning protocol), in a randomised order. Each participant attended for scanning wearing minimal clothing and having fasted overnight, refrained from exercise in the past 24 h and voided their bladders. Level of agreement, comparing NAHNES to Nana protocol was assessed using an intra-class correlation coefficient (ICC), concordance correlation coefficient (CCC) and percentage change in mean. Limit of agreement comparing the two protocols were assessed using plots, mean difference and confidence limits. Participants were asked to indicate the protocol they found most comfortable.

Results. When assessing level of agreement between protocols both the ICC and CCC scores were very high and ranged from 0.987 to 0.997 for whole body composition, indicating excellent agreement between the Nana and NHANES protocols. Regional analysis (arms, legs, trunk) ICC scores, ranged between 0.966 and 0.996, CCC ranged between 0.964 and 0.997, change in mean percentage ranged between −0.58% and 0.37% which indicated a very high level of agreement. Limit of agreement analysis

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using mean difference ranged between −0.223 and 0.686 kg and 95% CL produced results ranging between −1.262 kg and 1.630 kg. The majority (80%) of participants found the NHANES positioning protocol more comfortable.
Discussion. This study reveals a strong level of agreement as illustrated by high ICC's and CCC's between the positioning protocols, however systematic bias within limit of agreement plot and a large difference in 95% confidence limits indicates that the protocols should not be interchanged when assessing an individual. The NHANES protocol affords greater participant comfort.

Subjects Drugs and Devices, Epidemiology, Kinesiology, Nutrition, Radiology and Medical Imaging
Keywords DXA, DEXA, Level of agreement, body composition

INTRODUCTION

Tissue composition assessment and analysis is commonly undertaken by using dual-energy X-ray absorptiometry (DXA) (*Nana et al., 2012*). The need for a device to accurately and reliably measure bone mineral density as an indicator of an individual's bone health, led to the development and implementation of the DXA scanner (*Lewiecki, 2005*). Dual energy X-ray absorptiometry emits energy sources that are absorbed at different degrees of attenuation relative to the type of tissue they encounter; thus enabling clear imagining of different tissues (fat mass, lean mass and bone) based upon the distinctive elements of these tissues (*Rothney et al., 2009*). Due to these distinct properties of measurement, the DXA scan calculates an individual's total body composition (BC), together with an individual's regional BC; thus, the DXA is a popular instrument in research and clinical settings. Furthermore, DXA produces 0.004 mSv of radiation in each BC scan, equating to less than 1% of the maximum radiation dosage of 5 mSv in a year, as described by Australian Radiation Protection and Nuclear Safety Agency (*ARPANSA, 2005*). Therefore, the minimal level of radiation from DXA scans enables researchers and clinicians to widely use this instrument to assess BC on a regular basis. Research drawn from BC scans has assisted clinicians and researchers to further their understanding of a number of conditions, including obesity and undernourished individuals (*Lee & Gallagher, 2008*). When applying BC scanning to athletes, it has been identified that those with higher muscle mass in pre-season, have a decreased likelihood of suffering bone related injuries during the season (*Georgeson et al., 2011*). Nevertheless, it is important to note that the DXA's reliability must be ascertained prior to statistical data being extracted, analysed and applied within a clinical and or sporting population.

In previous studies a variety of statistical analysis methods have been undertaken including intra-class correlation coefficients (ICC), percentage change and Pearson correlations to assess the reliability of the DXA, all of which have found DXA to be reliable (*Bilsborough et al., 2014*; *Climstein et al., 2015*; *Colyer et al., 2016*; *Covey, Berry & Hacker, 2010*; *Covey et al., 2008*; *Kerr et al., 2016*; *Lohman et al., 2009*; *Moon et al., 2013*; *Nana et al., 2012*; *Nana et al., 2013*; *Smith-Ryan et al., 2017*). However higher reliability is found in studies that account for biological and technical errors, especially the use of a reproducible positioning protocol. The National Centre for Health Statistics, National Health and Nutrition Examination Survey (NHANES) body composition positioning protocol (NHANES, 2013) and the Nana positioning protocol, founded by Alisa Nana, are the two most popularly used protocols (Nana et al., 2012). It is important to note the Australian and New Zealand Bone Mineral Society (ANZBMS) employs the same body position as the NHANES positioning protocol.

F Shiel et al. (2017, unpublished data) have systematically assessed studies using the Nana and NHANES positioning protocols and concluded that there is a high level of evidence and excellent reliability for the Nana positioning protocol, and a moderate level of evidence but excellent reliability for the NHANES, and therefore the Nana protocol should be considered the gold standard for BC DXA scanning. Kerr et al. (2016) is the only study to date which has compared the Nana and NHANES positioning protocols, concluding that the Nana protocol's reliability is superior in assessment of regional BC, fat mass (FM) and bone mineral content (BMC). This study also recommended that positioning protocols should not be interchanged, and proposes that the Nana positioning protocol is more comfortable for the participant (Kerr et al., 2016). However, it should be noted that the Kerr study has used modified versions of the original protocols, which may have altered the participants perceived comfort level during the scan.

As such the primary aim of our study is to conduct an independent comparison of the Nana and NHANES positioning protocols in terms of results and level of agreement. The finding of this research will either strengthen the findings suggesting the Nana protocol produces superior results or increase the level of evidence for the NHANES protocol. Additionally, this study aimed to assess which of the two main positioning protocols identified in the published literature is more comfortable.

METHODS

Study overview

During a single session, each participant underwent a total body scan twice, being repositioned between each scan. The two scans consisted of one using the Nana positioning protocol, with feet and hands positioned in radio-opaque pads; the other scan utilized the NHANES positioning protocol scan, where the hands are positioned faced down on the scanning bed. The order of the positioning protocol scans was randomised. Each participant was asked to choose which positioning protocol, Nana or NHANES, was the most comfortable, and why they selected that positioning protocol.

Participants

Fifteen males and fifteen females ($n = 30$) were recruited from the local university and the greater public to partake in this comparative study. Thirty participants were selected based upon the previously published recommendations for reliability studies (Lexell & Downham, 2005). Participants underwent an anthropometrical analysis of height (to the closest 0.1 cm) using a medical stadiometer (Harpenden, Holtain Limited, Crymych, UK) and mass (to the closest 0.1 kg) on medical scales (WM202, Wedderburn, Bilinga,

Table 1 Participant characteristics.

	Males ($n = 15$)	Females ($n = 15$)	Group ($n = 30$)
Age (yr)	27.8 ± 7.2	31.3 ± 11.9	29.6 ± 10.1
Height (cm)	178.7 ± 7.3	164.7 ± 8.9	171.7 ± 10.7
Mass (kg)	78.9 ± 8.8	62.4 ± 9.7	70.6 ± 12.4

Australia) prior to undergoing a BC scan on the DXA. Participant characteristics can be found in Table 1. Prior to partaking in the study, all participants were informed of the testing procedures and signed a consent form. The study was granted ethics approval by Bond University Human Research Ethics Committee (RO15221).

Standardised baseline conditions

On the morning of the scan, the participant confirmed they had fasted overnight; rested and refrained from strenuous exercise for the previous 24 h; wore minimal clothing (males: underwear, females: underwear, sports bra or two piece bathers); bladder voided; as well as jewellery and metal removed, prior to scanning.

DXA instrument

BC was measured using a narrow angle fan beam Lunar Prodigy DXA machine (GE Healthcare, Madison, WI, USA) with automatic analysis performed using GE enCore 2016 software (GE Healthcare). DXA provides three-component approximation of bone tissue and soft tissue (lean tissue i.e., muscle) and fat tissue (*ANZBMS, 2014*). The DXA was calibrated daily prior to any scans using a phantom as per manufacturer's guidelines. The machine used for the study has previously been found to produce very high reliability for BMD (0.998), lean mass (0.989) and fat mass (0.995) (*Climstein et al., 2015*).

Standardised DXA operational protocol

All scans were performed by the same licensed researcher with all scans analysed automatically by the GE enCORE 2016 software. Two BC protocols were utilised, the NHANES positioning protocol and the Nana positioning protocol (Fig. 1). The NHANES protocol required the participant to be positioned in a supine position in the middle of the densitometry table with head straight, space between the arms and torso, palms flat on the table, and feet together secured by a strap (*NHANES, 2013*). When utilising the Nana positioning protocol, participants were centrally aligned in the scanning area with their feet placed in a custom-made foam block to maintain a consistent distance between the subject's feet (15 cm) in each scan. The custom-made foot blocks were made from styrofoam and were transparent under the DXA scan. Additionally, the subject's hands were placed in custom-made foam and plastic paddles to ensure a mid-prone position with a standardised gap (3 cm) between the palms and trunk. These hand paddles created minimal changes to the scan analysis (*Nana et al., 2012*). Additionally, a strap around the ankles was utilised as per the NHANES protocol, to ensure that the only difference between protocols was the positioning block/paddles.

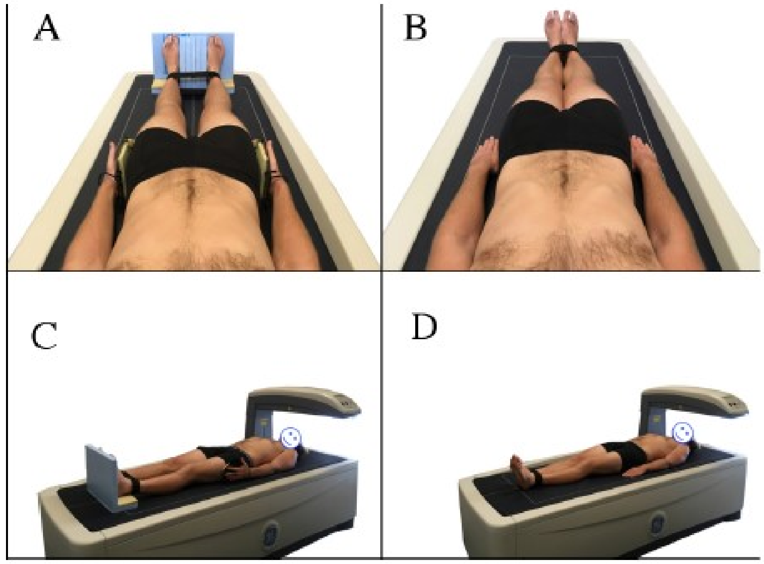

Figure 1 Nana positioning protocol (A, C) and NHANES positioning protocol (B, D).
Full-size DOI: 10.7717/peerj.3880/fig-1

Statistical analysis

IBM SPSS (version 24.0) and a custom reliability spreadsheet from Sportscience web site (http://www.sportsci.org) were used to analyse the data. Anthropometrical data were presented as means and standardised deviations. IBM SPSS 24 was utilised to assess Intra-class Correlation Coefficient (3, 1) with Confidence Intervals (CI), Concordance Correlation Coefficient (CCC) with 95% Confidence Limits (CL) and create Limit of Agreement analysis plots and assess mean difference and associated confidence limits. This specific ICC was selected based on the published work of *Trevethan (2016)*. Percentage change in mean and typical error expressed as coefficient of variation as a percentage (CV%) were calculated using the customised Sportscience spreadsheet.

RESULTS

All results comparing the Nana positioning protocol with the NHANES positioning protocol (Fig. 2) are presented in Table 2. When assessing the BC using two different positioning protocols; the results of the whole body (tissue, FM, LM and BMC) scans and all regional (arms, legs and trunk) scans were excellent based on ICC's and percentage change in mean statistics. The results are also illustrated in the Limit of Agreement analysis plots for whole body (Fig. 3) and Table 3 for all regions.

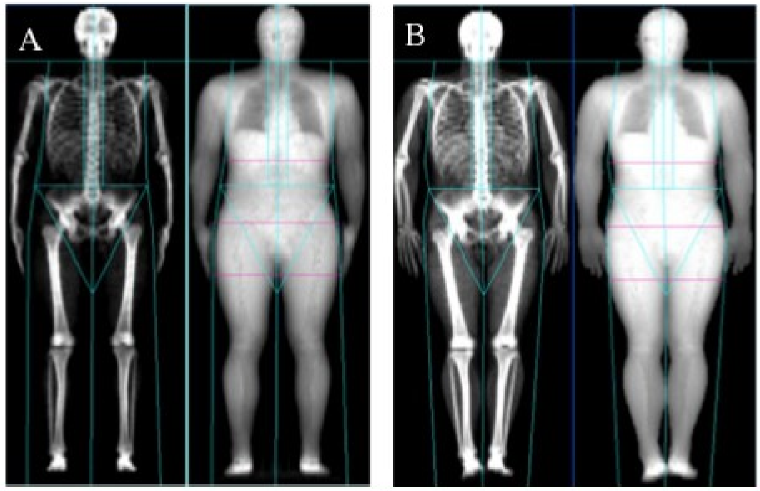

Figure 2 Nana positioning protocol (A) and NHANES positioning protocol (B).
Full-size DOI: 10.7717/peerj.3880/fig-2

Table 2 Level of agreement between Nana vs NHANES positioning protocols.

		% Δ in mean	Typical error as CV%	ICC	CI (95%)	CCC	CL (95%)
Whole body	Tissue	−0.47	0.10	0.987	0.970–0.994	0.987	0.976–0.993
	Fat	0.21	0.30	0.997	0.992–0.999	0.997	0.994–0.998
	Lean	−0.68	0.32	0.997	0.905 - 0.999	0.997	0.995–0.998
	BMC	0.06	0.03	0.990	0.586–0.998	0.989	0.983–0.994
Arms	Tissue	−0.32	0.19	0.982	0.745–0.995	0.982	0.968–0.989
	Fat	0.08	0.13	0.966	0.923–0.984	0.964	0.936–0.980
	Lean	−0.39	0.15	0.980	0.329–0.996	0.980	0.966–0.980
	BMC	0.01	0.01	0.979	0.876–0.993	0.994	0.989–0.997
Legs	Tissue	−0.58	0.38	0.984	0.822–0.995	0.983	0.971–0.990
	Fat	−0.10	0.19	0.992	0.983–0.996	0.992	0.986–0.996
	Lean	−0.49	0.30	0.987	0.837–0.996	0.987	0.977–0.992
	BMC	0.02	0.01	0.996	0.795–0.999	0.997	0.998–0.999
Trunk	Tissue	0.37	0.42	0.993	0.977–0.997	0.993	0.987–0.996
	Fat	0.22	0.29	0.991	0.975–0.996	0.991	0.983–0.995
	Lean	0.18	0.39	0.993	0.986–0.997	0.993	0.988–0.996
	BMC	0.02	0.02	0.973	0.841–0.991	0.972	0.951–0.984

Notes.
% Δ in Mean, percentage change in mean; CV, confidence variance; ICC, intra-class correlation coefficient; CI, confidence interval; CCC, concordance correlation coefficient; CL, confidence limit.

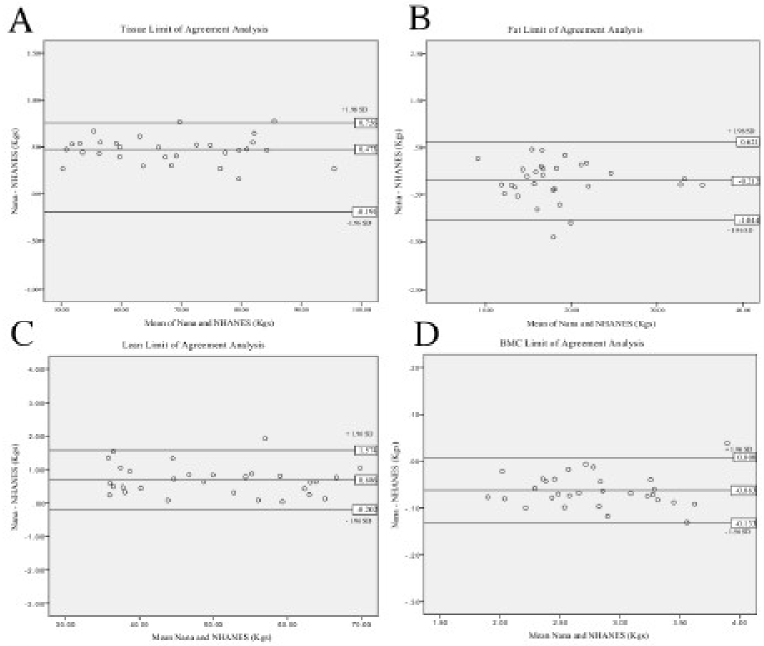

Figure 3 Limit of Agreement analysis for Nana versus NHANES whole body positioning protocols. Tissue analysis (A), fat analysis (B), lean analysis (C), BMC analysis (D).

Full-size DOI: 10.7717/peerj.3880/fig-3

Percentage change in mean when comparing the two protocols has produced results that range between −0.68% and 0.37%. Trunk was the regional area with the smallest variance of the four sites (whole body, arms, legs and trunk) as described in Table 2, with results ranging from 0.02% to 0.37%. Whole body scans produced the largest variance, with results ranging from −0.68% to 0.21%.

The typical error expressed as CV% of the agreement between the positioning protocols produced results ranging between 0.01% and 0.42%. The parameter of BMC was assessed to produce the smallest typical error across the four different sites (whole body, arms, legs and trunk). The tissue parameter was found to be the highest in three of four assessment sites (arms, legs and trunk).

A very high level of agreement between the two positioning protocols is evident through an ICC ranging between 0.966 and 0.999. Whole body fat mass-produced the highest ICC of 0.997, with a 95% CI [0.992–0.999]. The fat mass of the arms produced the lowest ICC of 0.966, with a 95% CI [0.923–0.984].

Table 3 Limit of agreement between Nana vs NHANES positioning protocols.

		Mean difference	Lower CL	Upper CL
Whole body	Tissue	0.473	−0.191	0.756
	Fat	−0.212	−0.621	1.044
	Lean	0.686	0.202	1.574
	BMC	−0.063	−0.133	0.008
Arms	Tissue	0.321	0.193	0.836
	Fat	−0.074	−0.432	0.283
	Lean	0.396	0.014	0.807
	BMC	0.000	−0.020	0.021
Legs	Tissue	0.586	0.458	1.630
	Fat	0.099	0.420	0.618
	Lean	0.488	0.350	1.327
	BMC	−0.005	−0.030	0.020
Trunk	Tissue	0.366	0.806	1.538
	Fat	−0.223	−1.017	0.572
	Lean	−0.176	−1.262	0.911
	BMC	−0.022	−0.071	0.027

Notes.
CL, Confidence Limit (95%).

Additional to the ICC, the CCC illustrates very good results with the results ranging between 0.964 and 0.997. The whole body lean mass produced the highest result of 0.997 with 95% CL of 0.995–0.998. Similar to the ICC result the fat mass of the arms produced the lowest correlation of 0.964 with 95% CL 0.936–0.980.

Limit of Agreement analysis plots (Fig. 3) for the whole body reveal a bias between the two measures when assessing tissue as the zero value lies outside of the interval. This indicates that the Nana protocol consistently produced larger values than the NHANES protocol. Limit of agreement analysis using mean difference between the protocols ranged between −0.223 and 0.686 kg across the parameters with arm measures the smallest difference. The 95% CL produced results ranging from −1.262 kg for the lower limit up to 1.630 kg for the upper limit. All mean differences fell within the define CL except for the leg fat assessment.

When questioned about which protocol was the more comfortable, 24 out of 30 participants (80.0%) chose the NHANES positioning protocol as the more comfortable of the two protocols assessed.

DISCUSSION

The primary aim of this study was to focus upon technical error associated with positioning and establish the level of agreement between the two identified positioning protocols. This study also sought to identify which DXA scan positioning protocol was the more comfortable for participants. In this study, we conducted all scans of BC using a Lunar DXA machine, located at Bond Institute of Health & Sport. To minimise the chance of technical error, one licensed researcher (qualified through ANZBMS) conducted all thirty scans as recommended for reliability studies (*Lexell & Downham, 2005*). To further decrease the chance of error affecting the results, biological factors such as time of day of scanning, hydration, exercise and food metabolism have been identified and accounted for.

This study found that the level of agreement between the Nana and the NHANES positioning protocols was very high when using a variety of statistics including percentage change in mean, accompanied with typical error, or ICC, accompanied with CI. The percentage change in mean findings of this study for the whole body (tissue −0.47%, FM 0.21%, LM −0.68%, BMC 0.06%) is similar to the results of the previous study comparing the two protocols (tissue −0.4%, FM −2.8%, LM 0.3%, BMC −0.7%) (*Kerr et al., 2016*). The results of this study suggest that the level of agreement between the two protocols when doing regional analysis is also very good however these results are opposed to previously published research that conclude there is a large difference between protocol results (*Kerr et al., 2016*).

The assessed percentage change in mean in this study is smaller across the all parameters assessed except for whole body tissue mass in comparison to the only other study that has compared the two positioning protocols (*Kerr et al., 2016*). This may be due to the stringent methodology used in our study. As both studies have accounted for biological factors creating errors the source of difference can only be technical error. As such in this study, the NHANES protocol was followed as prescribed in NHANES Body Composition Procedures Manual 2013 (*NHANES, 2013*). The participant's feet were secured together with a strap and the hands were placed in a pronated position (palms down on the table), reducing the likelihood of movement artifacts. In comparison, the previous research conducted by Kerr and colleagues, the legs were secured with a strap but positioned a significant distance apart, possibly allowing for small amounts of internal rotation and adduction as these movements were not limited. Furthermore, the hands were held in a neutral position, possibly allowing for small rotational movements. The combination of these two adjustments to the prescribed NHANES positioning protocol could possibly have created movement artifacts and altered results.

This is the first study to use an ICC to assess the level of agreement between the two positioning protocols. Very high ICC results are deemed to be between 0.90 and 1.00 (*Munro & Visintainer, 2005*), and our results (0.996–0.999) fall within this described range. Additionally, the concordance correlation results (0.964–0.997) coupled with the ICC results indicated that the level of agreement between the two positioning protocols is very high, however this needs to be coupled with the mean difference and confidence limits analysis before deciding if the protocols are interchangeable.

The limits of agreement between the two positioning protocols when plotted into limit of agreement analysis plots (Fig. 3) reveals a systematic bias in the parameter of whole body tissue. The systematic bias illustrates that the Nana protocol consistently produces higher results than the NHANES protocol, possibly due to the use of the foam blocks used to secure the feet. Additionally, Table 3 reveals that the mean difference lies outside of the defined 95% confidence limits for the leg fat parameter, this is due to this parameter having a large difference between the standard deviation and the mean when comparing the protocols. Applying the limit of agreement findings clinically illustrates a large variance, for example if the participant's lean mass was 50 kg and mean difference 1.75 kg then this equates to 4% change. These factors indicate that the two positioning protocols should not be used interchangeably even though the ICC results are very high.

When assessing which positioning protocol (Nana or NHANES) was deemed the most comfortable; this study found that 24 out of 30 participants (80.0%) chose the NHANES positioning protocol to be the most comfortable; this result is in direct opposition to previous findings (*Kerr et al., 2016*). Upon closer inspection of the methods employed, it appears Kerr and colleagues altered the original NHANES and Nana positioning protocols, which would have affected the perceived comfort levels of participants. The modified version of the NHANES positioning protocol they employed, would have required muscular activation and control; therefore, decreasing the participant's perceived comfort. When using the Nana positioning protocol, a strap was added to the original Nana protocol, which secured the participants arms for approximately seven minutes during scanning; hence decreasing the muscular activation and increasing the participant's perceived comfort. In our study, the majority of participants who chose the NHANES as the most comfortable did so because they felt their hands and arms were in a more relaxed position.

The Nana positioning protocol, where the feet are placed in radio-opaque blocks to maintain plantargrade ankle position, allows for taller individuals to be scanned with a decreased risk of plantar flexion and the participant's feet moving outside the scanning field (*Nana et al., 2012*). Most individuals in our study over the height of 185 cm chose the Nana positioning protocol for comfort, and did so based on not having to actively maintain their foot in plantargrade during the scan. Additionally, the Nana positioning protocols' use of pads to maintain the hands in a midprone position allows for larger individuals (width wise) to be scanned more easily in comparison to the NHANES, where the individual's hands are pronated flat on the table.

Future research needs to investigate if certain positioning protocols are more applicable for different participants dependent upon their size. Furthermore, more research is required to ascertain the difference between the positioning protocols when using regional analysis.

The implications for clinical practice are that the decision of which positioning protocol to employ should be based on comfort, i.e., the size of the participant's and not purely on the level of evidence for the protocols as both protocols produce very good results. As such, the NHANES protocol should be the first choice when scanning based on the comfort findings, however the Nana protocol provides a fantastic alternative for larger individuals.

CONCLUSION

When all sources of biological and technical errors have been accounted for, the Nana and NHANES positioning protocols both produce a very high level of agreement as demonstrated by very high results. However, the systematic bias revealed in the limit of agreement plot and the large 95% CL indicated that the two protocols should not be used interchangeably. Anecdotally, the NHANES positioning protocol was more comfortable.

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ADDITIONAL INFORMATION AND DECLARATIONS

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Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Flinn Shiel conceived and designed the experiments, performed the experiments, analyzed the data, contributed reagents/materials/analysis tools, wrote the paper, prepared figures and/or tables, reviewed drafts of the paper.
- Carl Persson conceived and designed the experiments, performed the experiments, analyzed the data, contributed reagents/materials/analysis tools, wrote the paper, reviewed drafts of the paper.
- Vini Simas performed the experiments, reviewed drafts of the paper.
- James Furness conceived and designed the experiments, contributed reagents/materials/analysis tools, reviewed drafts of the paper.
- Mike Climstein contributed reagents/materials/analysis tools, reviewed drafts of the paper.
- Ben Schram conceived and designed the experiments, reviewed drafts of the paper.

Human Ethics

The following information was supplied relating to ethical approvals (i.e., approving body and any reference numbers):

The Bond University Human Research Ethics Committee granted approval for this study to take place. Approval number: RO15221.

Data Availability

The following information was supplied regarding data availability:

The raw data has been supplied as Data S1.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.3880#supplemental-information.

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Appendix VI: Reliability and Precision of the Nana Protocol when assessing Body Composition using Dual Energy X-Ray Absorptiometry – published version

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Human Kinetics
ORIGINAL RESEARCH

Reliability and Precision of the Nana Protocol to Assess Body Composition Using Dual Energy X-Ray Absorptiometry

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The Nana positioning protocol is widely used to position participants to minimize technical error when undertaking body composition scanning and analysis with a Dual energy X-Ray absorptiometry (DXA) machine. Once biological and technical errors are accounted for, the only variation in test–retest results is from statistical fluctuation or machine error. Therefore, the aim of this study is to assess the test–retest reliability of the Nana positioning protocol and establish the smallest real difference percentage (SRD%). A gender-balanced group of 30 participants (15 males, 15 females) underwent two scans in succession using the Nana positioning protocol, with repositioning between scans. Percentage change in mean with typical error, Intraclass Correlation Coefficients (ICC), and standard error measurement percentage (SEM%) were used to identify the test–retest reliability and error rate of these protocols. Additionally, SRD% was calculated to assess the point at which clinically important changes occurred in a participant. The reliabilities of the whole body and regional scans were excellent. Percentage change in mean ranged between 0.00% and 0.23%. High reproducibility of the Nana positioning protocol was evident through an ICC ranging between 0.966–1.000. Additionally, typical error, SEM%, and SRD% were all low. Interestingly, fat mass was associated with the largest fluctuations observed to be associated with any of the parameters assessed. When all sources of biological and technical errors have been accounted for, the Nana positioning protocol has excellent test–retest reliability and produces low SEM% and SRD%.

Keywords: DXA, smallest real difference, test re-test

Dual energy X-ray absorptiometry (DXA) uses a machine originally developed to provide information about bone mineral density, with the additional capability to assess and analyze body composition (BC) while imparting only low levels of radiation (less than a thousandth of the maximum recommended dosage of 5mSv; Australian Radiation Protection and Nuclear Safety Agency [ARPANSA], 2005; Bazzocchi et al., 2016; Lewiecki, 2005; Nana et al., 2012). The distinct characteristics of lean mass (LM), fat mass (FM), and bone when scanned with DXA enable clinicians and researchers to gain a greater understanding of both the

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pathogenic processes involved in a variety of conditions (obesity, diabetes, undernourished individuals, renal, gastrointestinal diseases) and the physiological changes in healthy populations associated with the process of growth and aging (Bazzocchi et al., 2016; Lee & Gallagher, 2008; Rothney et al., 2009). Body composition scans are also used extensively in athletic populations to investigate physiological and para-physiological conditions affecting athlete performance (Bazzocchi et al., 2016; Georgeson et al., 2011).

DXA results for body composition have been found to be reliable in assessments of test–retest reliability that have used a wide variety of reliability statistics (Bilsborough et al., 2014; Colyer et al., 2016; Covey et al., 2010; Covey et al., 2008; Kerr et al., 2016; Lohman et al., 2009; Moon et al., 2013; Nana et al., 2012, Nana et al., 2013; Smith-Ryan et al., 2017). However, in order to produce the most reliable results, provisions in methodology are required to minimize the chance occurrence of errors, both biological and technical, that create false or misleading results (Hangartner et al., 2013). The most important provision to minimize technical errors is to use a consistent manner in which participants are positioned. As such, two positioning protocols exist—the National Health and Nutrition Examination Survey (NHANES) Body Composition positioning protocol of the National Centre for Health Statistics, and the Nana positioning protocol designed and described by Alisa Nana (Nana et al., 2012; NHANES, 2013). These two positioning protocols are used to minimize the movement of the participant during scanning, which creates artifacts, and consistently produce higher reliability scores than DXA scanning without a repeatable positioning protocol (Bilsborough et al., 2014; Colyer et al., 2016; Covey et al., 2008, 2010; Kerr et al., 2016; Lohman et al., 2009; Moon et al., 2013; Nana et al., 2012, 2013; Smith-Ryan et al., 2017).

Upon reviewing (critical appraisal and level of evidence) studies of reliability of the DXA results yielded using each of these protocols, we found there was a high level of evidence and very high reliability for the Nana positioning protocol even though all studies using the Nana protocol involved Alisa Nana, the founder of the protocol. The NHANES protocol had a moderate level of evidence but suggested very high reliability.

Additionally, in previous studies investigating the reliability of DXA measurements of body composition there has been inconsistent use of statistical procedures. To date, no study has included the calculation of smallest real difference (SRD) or smallest real difference percentage (SRD%), which constitute the benchmark statistical analysis used to determined whether a real change beyond measurement error has occurred at the defined confidence level (Beckerman et al., 2001; Chen et al., 2009). Previously authors have reported typical error (usually expressed as a coefficient of variation percentage [CV%]) or smallest worthwhile effect (SWE). There are inconsistencies in the definition of the SWE statistic, as most authors propose that the SWE can only be determined by consultation with participants who received the intervention and not by researchers or clinicians using statistical analysis in isolation; however, some authors have calculated it based simply on dividing the between-subject standard deviation by one-third (Ferreira et al., 2012, 2013; Herbert, 2000; Kerr et al., 2016; Nana et al., 2012, 2013).

On this basis, technical error was the primary focus of this study. Specifically, the aim of this study was to determine the test–retest reliability of DXA results obtained using the Nana positioning protocol to assess total body and regional BC.

Methods

Study Overview

In order to assess the reliability of the Nana positioning protocol, each participant was scanned twice using the DXA machine by a trained scanner, in a single session at Bond University, Gold Coast, Australia. Scanning was undertaken in accordance with the Nana positioning protocol (feet and hands positioned in radio-opaque pads). Each subject was repositioned between scans, with the total session running for approximately 15 minutes per participant.

Participants

Prior to commencing the research, this study was granted ethics approval by Bond University Human Research Ethics Committee (RO0000015221). Each subject was informed of all risks and the testing procedure, with the informed consent process taking place prior to scans proceeding. A gender-balanced group of 15 males and 15 females ($N = 30$) was enlisted from Bond University on the Gold Coast, Australia, and from the wider public of the Gold Coast community. Participants were included based on the inclusion criteria that participants wholly physically fitted within the scanning area (197 cm × 60.5 cm) so as to avoid minimize the confounding variable of segmental scans (i.e., participant too tall or too wide for scanning area).

The participant demographics ($M \pm SD$) were females (n = 15), age = 31.3 ± 11.9 years, height = 164.7 ± 8.9 cm, mass = 62.4 ± 9.7 kg; and males (n = 15), age = 27.8 ± 7.2 years, height = 178.7 ± 7.3 cm, mass = 78.9 ± 8.8 kg. The number of subjects recruited was based on recommendations regarding sample sizes published in previous reliability studies (Lexell & Downham, 2005). A Stadiometer (Harpenden, Holtain Limited, Crymych, UK) and scales (WM202, Wedderburn, Bilinga, Australia) were utilized to undertake an anthropometric analysis of height and mass of each subject prior to BC scanning on the DXA machine.

Standardized Baseline Conditions

The subject reported for their morning scan having fasted overnight; refrained from exercise; and with their bladders voided. Male subjects wore minimal attire (i.e., underwear), whereas female subjects wore either two-piece underwear or bathers, as they wished. Furthermore, all subjects were required to remove any metal from their bodies and clothes.

DXA Instrument and Operation. The Lunar Prodigy DXA machine (GE Healthcare, Madison, WI) was calibrated every day according to the manufacture's guidelines, using a phantom. A single Australia and New Zealand Bone and Mineral Society (ANZBMS) densitometry qualified scanner performed each BC scan using the narrow angle fan beam DXA machine, and thereafter used the GE enCORE 2016 software (GE Healthcare) to analyze the data (Figure 1).

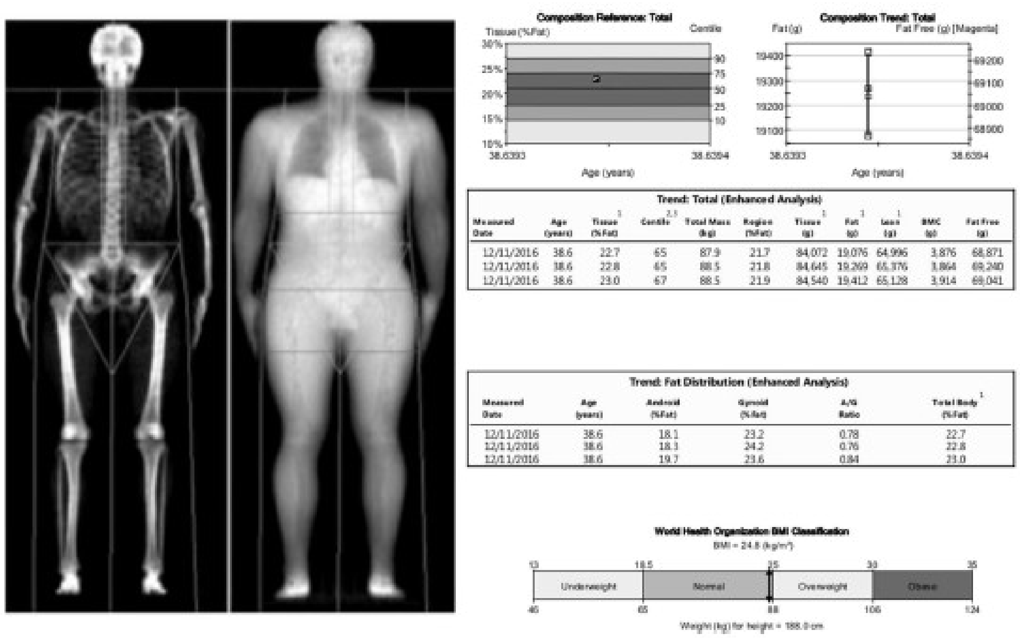
Nana Body Composition Positioning Protocol. During each scan, the Nana positioning protocol requires the subject's feet to be placed on a transparent styrofoam block, which is custom-made to keep a consistent distance of 15 cm between the feet; together with a strap around the ankles to keep movement minimal, and reduce artifacts (Nana et al., 2012). The subject is also placed centrally and in a supine position, with custom-made foam and plastic paddles used to position the subject's hands in a mid-prone position with a consistent gap of 3 cm between the inside of the hands and the trunk; again, the hand paddles reduced the risk of any movements (Figure 2; Nana et al., 2012).

Statistical Analysis

This study used a range of statistical approaches to collect, analyze, and present data. IBM SPSS 24 and custom-made spreadsheets from the Sportsscience website (www.sportsci.org) aided with determining percentage change in mean, confidence intervals (CI), typical error as CV%, standard error of measurement percentage (SEM% = (($\sqrt{}$mean square error from ANOVA)/mean) × 100%), and smallest real difference percentage (SRD% = ((1.96 × SEM × $\sqrt{2}$)/mean) × 100%) (Lexell & Downham, 2005). Intraclass Correlation Coefficients (type 3.1) were calculated as the primary measure of level of agreement between paired results using IBM SPSS 24 (Trevethan, 2017). Bland Altman plots were also generated and means and standard deviations were established for anthropometric data.

Results

All the collated results from the Nana positioning protocol test–retest reliability analysis are presented in Table 1. When assessing the BC on two different occasions with repositioning of the participant between scans, the reliabilities of the whole body (Tissue, FM, LM, and BMC) and all regional (arms, legs, and trunk) scan results were very high. Additionally, these results



Trend: Total (Enhanced Analysis)

Measured Date	Age (years)	Tissue (%Fat) [1]	Centile [2,3]	Total Mass (kg)	Region (%Fat)	Tissue (g) [1]	Fat (g) [1]	Lean (g) [1]	BMC (g)	Fat Free (g)
12/11/2016	38.6	22.7	65	87.9	21.7	84,072	19,076	64,996	3,876	68,871
12/11/2016	38.6	22.8	65	88.5	21.8	84,645	19,269	65,376	3,864	69,240
12/11/2016	38.6	23.0	67	88.5	21.9	84,540	19,412	65,128	3,914	69,041

Trend: Fat Distribution (Enhanced Analysis)

Measured Date	Age (years)	Android (%Fat)	Gynoid (%Fat)	A/G Ratio	Total Body (%Fat) [1]
12/11/2016	38.6	18.1	23.2	0.78	22.7
12/11/2016	38.6	18.3	24.2	0.76	22.8
12/11/2016	38.6	19.7	23.6	0.84	23.0

Figure 1 — Nana positioning protocol analysis.

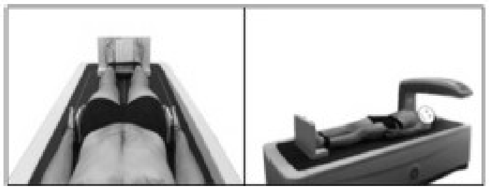


Figure 2 — Nana positioning protocol.

are also demonstrated in the Bland Altman plots (Figure 3), displaying close precision in all areas.

Percentage change in mean of the Nana positioning protocol ranged between −0.23% and 0.23%. Arms were the regional area with the smallest variance in the parameters (Table 1), with results ranging from −0.02% to 0.02%. The trunk had the largest variance, with results ranging from −0.23% to 0.12%.

The typical error, expressed as CV%, when using the Nana positioning protocol ranged between 0.01% and 0.75%. The arms showed the smallest typical error (Table 1), ranging between 0.01% and 0.11%; whereas for other body areas the typical error ranged from 0.03% to 0.75%, with the whole body LM producing the largest value of 0.75%.

High reproducibility of the Nana positioning protocol is evident in the ICC, ranging between 0.966 and 1.000. FM consistently presented the lowest ICC for whole body and regional scans except for trunk BMC, which produced the lowest ICC of 0.966 (95% CI0.931–0.984). Whole body tissue produced the highest ICC of 1.000 (95% CI 1.000–1.000).

The SEM% reflected the results of the ICC, with FM results consistently showing the highest SEM%. Tissue mass of the whole body produced the lowest SEM% scores (Table 1).

Smallest real difference percentages (SRD%) also followed the pattern of ICC and SEM%, with FM consistently displaying the highest results, ranging between 5.9% and 11.1%. Tissue, LM and BMC illustrated an overall low SRD% score throughout, except for the regional trunk of BMC, which indicated a high SRD% of 9%.

Discussion

The aim of this study was to provide an unbiased assessment of the reliability of the Nana positioning protocol and establish the SRD% of the Nana positioning protocol. The Nana positioning protocol produced excellent test–retest reliability results when the parameters of tissue mass, FM, LM, and BMC were assessed in

Table 1 Nana Positioning Protocol Test–Retest Reliability

	% Δ in mean	Typical error as CV%	ICC	CI (95%)	SEM%	SRD%
Whole body						
Tissue	0.03	0.14	1.000	1.000–1.000	0.2	0.6
Fat	0.23	0.36	0.996	0.990–0.998	2.1	5.9
Lean	−0.03	0.75	0.996	0.991–0.998	1.5	4.1
BMC	0.02	0.03	0.997	0.993–0.999	1.1	3.1
Regional						
Arms						
Tissue	0.00	0.10	0.998	0.996–0.999	1.1	3.0
Fat	−0.02	0.08	0.986	0.972–0.994	3.8	10.6
Lean	0.02	0.11	0.997	0.995–0.999	1.7	4.7
BMC	0.00	0.01	0.996	0.992–0.998	1.6*	4.5*
Legs						
Tissue	0.07	0.29	0.996	0.991–0.998	1.2	3.3
Fat	0.10	0.20	0.992	0.982–0.996	3.0	8.3
Lean	−0.03	0.29	0.995	0.989–0.998	1.7	4.6
BMC	0.00	0.01	0.996	0.998–0.999	0.8*	2.3*
Trunk						
Tissue	−0.10	0.32	0.997	0.994–0.999	1.0	2.8
Fat	0.12	0.33	0.990	0.979–0.995	4.0	11.1
Lean	−0.23	0.45	0.991	0.981–0.996	2.0	5.5
BMC	0.01	0.03	0.966	0.931–0.984	3.3*	9.1*

Note. % Δ in Mean = percentage change in mean; CV = confidence variance; ICC = intraclass correlation coefficient; CI = confidence interval; SEM% = percentage standard error of measurement; SRD% = percentage smallest real difference.
*Assessed in milligrams.

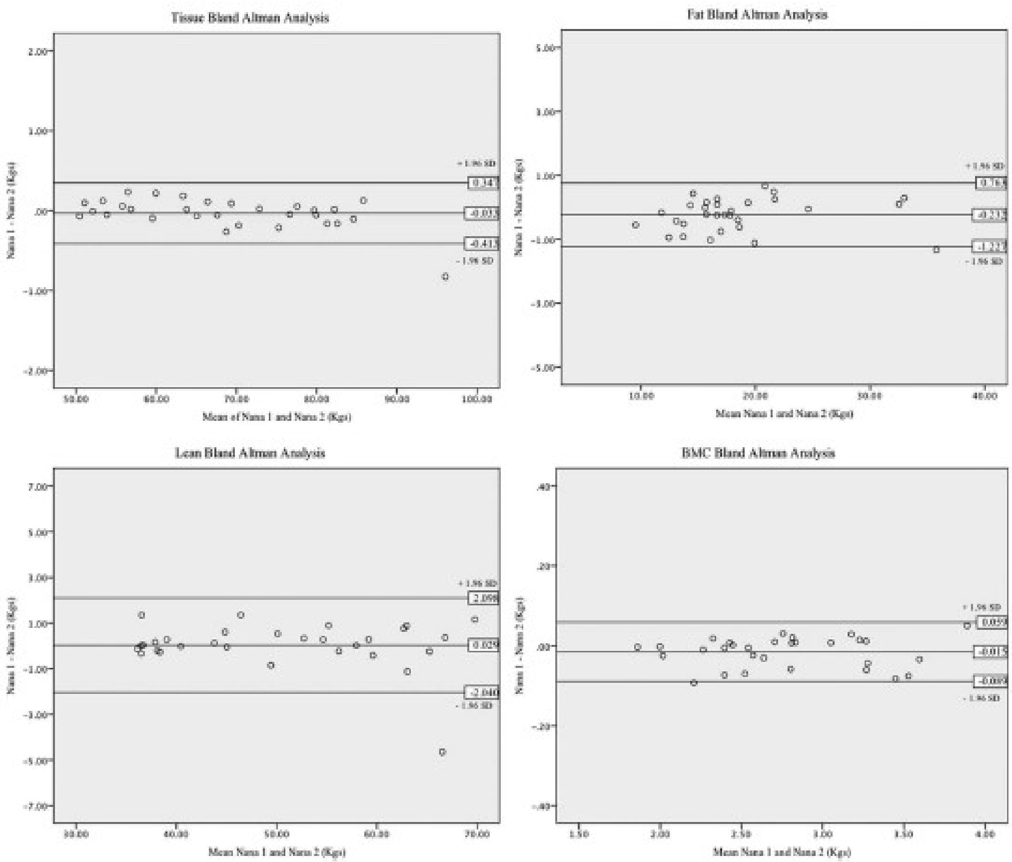


Figure 3 — Bland Altman plots for whole body Nana versus Nana positioning.

the total body, and in the regions of the arms, legs, and trunk. These results confirm the findings of previous research indicating that the Nana positioning protocol is a reliable positioning protocol when using a DXA machine to assess body composition (Kerr et al., 2016; Nana et al., 2012, 2013).

In this study, when percentage change in mean was used to assess reliability, the Nana positioning protocol produced similar results as previous studies that have used this statistic (Kerr et al., 2016; Nana et al., 2012, 2013). The actual figure of change in this study's result was consistently lower in comparison to those from previous studies that utilized the Nana positioning protocol (Kerr et al., 2016; Nana et al., 2012, 2013). This may be possibly due to the strict methodology followed and that the machine used was relatively new. The results fluctuated among studies as to which parameter (tissue, FM, LM, or BMC) produced the smallest change in mean from zero. Only the parameters of tissue mass when assessed on the whole body, together with BMC when assessed in the legs, produced results that were similar across all the studies. Consequently, these produced the smallest change in mean scores from zero in all studies.

When using percentage change in mean, it is required to present the typical error, this has usually been presented as a percentage of typical error otherwise known as a CV % (Hopkins, 2000; Hopkins et al., 2009). The CV% results of this study typically were smaller values when compared to other studies (Kerr et al., 2016; Nana et al., 2012, 2013), and this is likely due to the provisions in methodology used to reduce effects of biological and technical error. Once again differences occurred in regards to which parameter produced the smallest percentage typical error. It was found that only BMC in the legs produced the same results across all studies.

This study is the only study so far to include ICC results for all parameters in whole body and regional body areas. The ICC results of this study ranged between

0.966 and 1.000, demonstrating very high reliability (Munro & Visintainer, 2005). Other studies have presented ICC ranging between 0.40 and 0.99 (Nana et al., 2012, 2013). These results varied significantly as they have not reported ICC for individual variables but instead have reported overall figures.

To our knowledge, this is the first time that SRD% has been used when assessing use of DXA to measure BC. In this study, the SRD% was calculated to fall between 0.6% and 5.9% (whole body) and 2.3% and 11.1% (regional), thus providing an indication of the point at which real change occurs. Using SRD% produced results that were similar to the other studies that have used SWE, in that FM produced the largest figure that may be attributed to statistical error or fluctuation before a real change can be confidently assessed. As such SRD% should be calculated on each individual machine if longitudinal analysis of BC is being undertaken.

As the most fluctuation of SRD% scores occurred in the trunk and arm regions, the authors postulate this may be due to automatic region of interest lines were applied automatically and adipose tissue may have encroached over the region of interest line into another region (i.e. the arm fat may have been assessed in both the arm and trunk in one scan but may have been only in the arm region on the next scan). To address this possible issue, future research should be undertaken with ROI adjusted and standardized between patients to ensure that the region of interest line follows the defined anatomical landmarks and tissue does not encroach into other regions.

In summary, once biological and technical errors have been justified, the Nana positioning protocols produced very high test–retest reliability, and therefore can be the trusted choice for clinicians assessing an individual's BC. Additionally, we urge future clinicians and researchers using the Nana positioning protocol to establish the SRD%. This calculation will enable a scanner to determine the figure at which a change in results can confidently be attributed to a true change of the participant between test–retest, and not due to statistical fluctuation or error.

Acknowledgments

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Appendix VII: Bone Health of Middle-Aged and Older Surfers – published version

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ORIGINAL RESEARCH

Bone health of middle-aged and older surfers

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Purpose: Given the lack of research investigating surfing and bone health, we aimed to assess the bone mineral density (BMD) of middle-aged and older surfers.

Patients and methods: In a cross-sectional observational design, we compared a group of middle-aged and older surfers to a group of non-surfers, age- and sex-matched controls. Participants were males, aged between 50 and 75 years. Volunteers were assessed for body mass index, bone-specific physical activity questionnaire (BPAQ) scores, daily calcium intake, and alcohol intake. Primary outcomes included BMD at the femur and lumbar spine (LS), and T-score, assessed via dual-energy X-ray absorptiometry. Bone biomarkers were also analyzed.

Results: A total of 104 participants (59 surfers and 45 controls) were assessed. Groups were similar with regards to all demographic characteristics except for percentage of lean mass (higher in surfers, mean difference [MD] +2.57%; 95% CI 0.05–5.09; p=0.046) and current BPAQ score (lower in surfers; MD −0.967; 95% CI −0.395 to −1.539; p=0.001). Surfers had a mean surfing experience of 41.2 (SD±11.8) years and mean surfing exposure of 26.9 (SD±15.0) hours/month. Controls were divided into two groups, according to their main physical activity: weight-bearing/high intensity (WBHI) and non-weight-bearing/low intensity (NWBLI). When compared to NWBLI controls, surfers had higher LS BMD (MD +0.064; 95% CI 0.002–0.126; p=0.041) and higher T-score (MD +0.40; 95% CI 0.01–0.80; p=0.042); however, surfers had a lower T-score than the WBHI group (MD −0.52; 95% CI −0.02 to −1.0; p=0.039). No other differences were found between groups.

Conclusion: The findings of this study support our hypothesis that regular surfing may be an effective physical activity for middle-aged and older men to decrease bone deterioration related to aging, as we identified positive results for surfers in relation to primary outcomes.

Keywords: surfing, bone mineral density, osteoporosis, DXA, preventive medicine, sports medicine

Introduction

A physically active lifestyle is recognized as a preventative strategy for age-related bone deterioration that can lead to osteopenia and osteoporosis. A vast variety of exercise modes has been evaluated; however, not all types of exercise promote positive effects on bones.[1,2] For instance, walking, swimming, and cycling are associated with little, no, or even a negative effect on bone health.[3–5]

Surfing is a popular recreational activity and competitive sport. It is also one of the fastest growing sports in the world with participants estimated at 37 million worldwide in 2012,[6] a statistic which has more than doubled if compared to the 18 million surfers estimated in 2002.[7] Surfing is recognized as a quasi-weight bearing (ie, having a partial load-bearing component) aquatic-based physical activity.[8,9] Time-motion analysis of recreational surfers has indicated that surfers typically

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spend only 3 mins standing up (ie. weight-bearing) on the board (ie, actually surfing) in a 60-min surf session.[8] Such a short period of weight-bearing may not apply sufficient stimulus for positive bone remodeling. It could, therefore, be expected that participants in this aquatic activity may have an imbalance between osteoclastic (bone resorption) and osteoblastic (bone production) activity, resulting in degradation of bone mineral density (BMD) and consequently exposing surfers to premature development of osteoporosis and increased risk of fractures.

Nonetheless, surfing requires a wide range of physical qualities in order to paddle-out, pass through waves, "catch" a wave, balance on the surfboard, and execute and complete surfing maneuvers. It is possible that these additional actions, requiring considerable muscle exertions, enhance the stimulus to bone applied during a surfing session. Only one study has previously investigated bone health in surfers,[10] and findings suggested that surfing may be advantageous for bone. However, this study had a small sample size and did not utilize standard clinical site testing (ie, femur and lumbar spine [LS]) for bone health; however, it suggests more data are required to examine the association.

Therefore, the bone health of surfers is unclear, as there is no consensus on the effect of long-term surfing on BMD. Additionally, should preventive measures and recommendations to reduce the risk of bone deterioration be in place for this cohort? Consequently, bone health of middle-aged and older surfers should be a principal concern for clinicians. The aim of the current study, therefore, was to compare femur and LS BMD of middle-aged and older long-term male surfers with non-surfers in a larger sample than previously examined. The results will begin to inform clinical decisions regarding exercise recommendations for the prevention of osteopenia and osteoporosis in older men.

Methods

Study design

This research used a cross-sectional observational design to compare middle-aged and older male surfers to non-surfing, age- and sex-matched controls. The study was approved by the Bond University Human Research Ethics Committee (BUHREC 15221).

Participants

Surfers were recruited through advertising in a local paper and from local boardrider clubs in the Gold Coast (GC) area (city of GC, Queensland, Australia). Additional support was obtained from surfing magazines, websites, and local surf shops in the GC area. Controls were recruited through advertisements at local community libraries, cafes, and clubs.

Eligibility criteria

Participants considered to be included in the study were males, aged between 50 and 75 years. Surfers were defined as those individuals who had been surfing for the past 15 years and were currently surfing regularly (at least twice a week). Surfers were excluded if they were currently participating in extensive resistance exercise, weight training or high impact activities, or if they were employed in or have been previously employed in a manual type of employment that would have a benefit for bone health. Participants in the control group were included if they were not surfers and did not have a history of surfing for more than 10 years.

For both groups, participants were excluded if they: had an existing diagnosis of osteopenia, osteoporosis, or any other medical condition known to affect bone health; had artificial bone implants (such as a hip replacement); had a history of hormone therapy; used any medication that could possibly affect bone density; were a current or past smokers; had a body mass index (BMI) over 30 kg/m^2 or under 21 kg/m^2; or had undergone a radiological examination which requires contrast dye within 7 days prior to the study, as perfusion imaging with dye is known to significantly affect BMD results.

All individuals who passed the initial screening were invited to participate in the study. The research took place at the Water Based Research Unit (WBRU), located at the Bond University Institute of Health and Sport (GC, Queensland, Australia). An explanatory statement and informed consent form were given to all participants upon arrival at the WBRU. Prior to providing written informed consent, all participants had the opportunity to ask any questions about the research and any of the testing procedures.

Procedures

At the WBRU, participants had their height and body mass measured and then completed two self-administered questionnaires. The bone-specific physical activity questionnaire (BPAQ)[11] quantified the participants' lifetime physical activity of relevance to bone, and it was calculated for current (cBPAQ), past (pBPAQ), and total (tBPAQ) scores. The second survey quantified current calcium intake, utilizing the calcium calculator from the International Osteoporosis Foundation (IOF) website.[12] A third questionnaire assessed their current alcohol intake, family history of osteoporosis, and surfing characteristics (the latter specifically for surfers). Participants then underwent a dual-energy X-ray absorptiometry (DXA) scan at the bone health and body composition (BC) laboratory, for BMD analysis of the non-dominant hip and LS. Additionally, BC was assessed via a total body scan.

Following the DXA scans, a randomly allocated participant subsample provided a blood sample for analysis of two bone turnover biomarkers: serum carboxy-terminal collagen crosslinks (sCTx) and serum procollagen type 1 N-terminal propeptide (sP1NP). A standard blood test was collected and analyzed by a commercial pathology laboratory (Sullivan Nicolaides Pathology, GC, Queensland, Australia), for this purpose.

Outcome measures

Height, mass, and BMI

Participants were requested to remove their shirt, slacks, shoes, and socks to enable assessment of their height, which was measured using a stadiometer (Harpenden, Holtain Limited, Crymych, UK) to the nearest 0.01 m. Mass was then measured to the nearest 0.1 kg using a standard digital weighing scale (WM202, Wedderburn, Bilinga, Australia). BMI was then calculated using the traditional method: BMI=weight/height^2 (kg/m^2).

Physical activity

The BPAQ[11] was used to capture past physical activity of relevance to bone across their whole lifetime, and specific to the previous 12 months. Physical activity was recorded by type and age when they participated, and the number of years they participated were recorded for each type. Information collected was entered into the BPAQ analysis software (freely available for download, http://www.fithdysign.com/BPAQ), generating current (cBPAQ), past (pBPAQ), and total (tBPAQ) physical activity scores (unitless) for each participant.

Calcium

Daily calcium intake was estimated using the IOF dietary questionnaire and the calcium calculator on the IOF website.[12] Results were recorded as percentage of recommended daily intake (%RDI) according to guidelines of Osteoporosis Australia.[13]

Alcohol

Participants were asked about the number of standard (std) drinks they normally consume in a typical week, as excessive amounts of alcohol are known to negatively affect bone health.[2,14]

BC, BMD and T-score

A DXA scan (General Electric, GE, Lunar Prodigy, Madison, WI, USA) was conducted for each participant in order to determine the primary outcomes (femur BMD, LS BMD, and T-score) and BC (fat and lean mass). The scanner was calibrated each morning prior to any scans using a manufacturer's "phantom" (quality assurance and quality control procedures). Prior to all DXA scans, participants were required to complete a short health questionnaire, to determine if for any reason the DXA scan should not take place. To avoid falsely elevated bone density, all metal objects were removed and participants were required to wear only light clothing. Participants were positioned according to the site that was to be measured. For the analysis of the LS, the participant lay supine on the scan bed, centered and straight, ensuring hips and shoulders were square, with the legs flexed over a support pad (supplied by the manufacturer), to create an angle of 60° to 90° between the table top and the participant's thighs. For the analysis of the hip (unilateral, non-dominant side), the participant lay supine with the legs in internal rotation (approximately 15°) and slight abduction. This positioning is important in order to minimize the visibility of the lesser trochanter and to maintain the femoral axis straight. Estimates of BC were obtained from the total body scan. For the total body scan, the participant's head was positioned directly below the horizontal line running across the top of the scan table. The entire participant's body was positioned within the lateral region or interest lines on the table. BC was analyzed to determine percentage of lean mass (%lean mass) and fat mass (%fat mass). Results were analyzed using the commercial software provided with the DXA machine (enCORE software, version 17, GE, Lunar Prodigy, Madison, WI, USA).

The DXA scan yielded BMD (g/cm^2) and T-score of the femur and LS, based on the regions of interest recommended by the International Society for Clinical Densitometry (ISCD) official position.[15] The T-score recorded was the lowest result obtained between the two regions and was used to classify the participant according to the WHO criteria for the diagnosis of osteoporosis (T-score greater than −1.0 is considered normal, T-score between −1.0 and −2.5 is considered osteopenia, and T-score below −2.5 is considered osteoporosis).[16]

Intra-tester reliability

Before conducting the study, intra-rater reliability and precision of DXA in evaluating BC and BMD was assessed using a sample of 30 individuals. Assessment of BC and BMD in the LS, femoral neck and total hip yielded measurements with high intra-rater reliability, and the results were published recently.[17,18]

Surfing group characteristics

Surfers were assessed with regard to surfing-specific characteristics, which included: surfing ability, as measured by the Hutt scale;[19] surfing experience in years; number of sessions per month; number of hours per session; surfing exposure (number of hours per session multiplied by number of sessions per month); stance while surfing (ie, "regular" if left foot forward or "goofy" if right foot forward); and type of surfboard (short, mini-mal/funboard or longboard).

Biochemical markers of bone turnover

Bone turnover markers sCTx (ng/L) and sP1NP (µg/L) were collected and analyzed via serum blood at a commercial pathology laboratory in a randomized subsample of participants. To date, the best marker for bone resorption is CTx,[20] as it is primarily associated with osteoclastic activity. The best marker for bone formation is P1NP, due to its wide usage and high utility for fracture prediction.[20,21] P1NP also has a shorter response time than other popular bone formation markers.[22] In addition to this, these biomarkers have recently been assessed in older surfers.[10]

Data analysis

Initially, continuous variables were tested for normality by assessing skewness, kurtosis, Q-Q plots, and the Kolmogorov–Smirnov test, and were summarized using means and SD, if normally distributed. Independent samples *t*-tests were performed on normally distributed variables to assess differences in mean scores between the surfing and control groups, for each of the outcome measures. For non-normally distributed variable where the skewness could not be corrected through transformations, Mann–Whitney-*U* tests were used to assess differences between the groups for each of the outcome measures. Categorical outcomes, specifically diagnosis of osteopenia or osteoporosis based on the T-score, were summarized using counts (n) and percentages (%); Chi-square test of independence was used to assess any difference between groups. Correlation analyses were also conducted between participant characteristics and outcome variables using the parametric Pearson's product-moment correlation, or the non-parametric Spearman's rank-order correlation test, depending on the data distributions. The one-way multivariate analysis of variance (MANOVA) was used to determine whether there were any differences between types of physical activity in relation to the continuous primary outcomes. Statistically significant results were followed-up with univariate one-way ANOVA for each outcome variable. Multiple regression analyses were used to examine the relationships between BPAQ scores and the outcome variables. When required, a log transformation was performed. The level of significance, alpha, was set *a*priori at 0.05 for all statistical tests. Results are presented as mean±SD unless otherwise stated. All analyses were performed with SPSS statistical software (Version 25.0 for Windows, SPSS Inc., Chicago IL, 2017).

Results

A total of 104 participants were eligible to participate in the study and were divided into two groups. Group 1 (surfers) consisted of 59 surfers, and group 2 (controls) consisted of 45 controls.

Surfers had a mean surfing experience of 41.2 years (SD±11.8), surfing on average 16 times per month (mean 16.1±7.3), each session lasting on average 1.7 hrs (mean 1.7±0.4), with a mean surfing exposure of 26.9 hrs/month (SD±15.0). Over 80% of the surfers considered themselves to have advanced surfing skills (Hutt rating of 6 or more), 54.2% used a shortboard, and 43% had a "regular" stance.

Participants' demographic characteristics are shown in Table 1. Groups were similar (ie, there were no significant differences between them) with regards to most of the demographic characteristics and measures of physical activity, BMD and BC (age, BMI, number of std drinks, calcium %RDI, %fat mass, pBPAQ score, tBPAQ score, femur BMD, LS BMD, and T-score). However, surfers had higher %lean mass (mean difference [MD] +2.57%; 95% CI 0.05–5.09%; p=0.046) and lower cBPAQ score (MD −0.967; 95% CI 0.395–1.539; p=0.001). On average, the lowest T-score was found at the femur for both groups (surfing group mean −0.6±0.8; control group mean −0.7±0.8; p=0.506). None of the participants were classified as having osteoporosis, based upon their T-scores; however, 41.3% of all participants were classified as having

Table 1 Demographic and other characteristics

Characteristics	Surfers (n=59)		Controls (n=45)		p-value
	Mean	SD	Mean	SD	
Age (years)	60.8	7.2	62.5	6.4	0.198
BMI (kg/m²)	26.0	2.0	25.9	3.5	0.762
Number of std drinks	7.8	6.4	6.6	6.0	0.370
Calcium intake (%RDI)	95.1	34.7	88.0	32.8	0.283
Lean mass (%)	69.8	5.1	67.3	7.2	0.046*
Fat mass (%)	27.3	5.4	29.8	7.4	0.067
cBPAQ score	0.551	0.101	1.518	1.903	0.001*
pBPAQ score	57.629	36.018	76.553	69.730	0.102
tBPAQ score	29.092	18.008	39.755	34.253	0.620
Femur BMD (g/cm²)	0.971	0.123	0.971	0.109	0.987
LS BMD (g/cm²)	1.243	0.107	1.203	0.114	0.087
T-score	−0.7	0.8	−0.8	0.8	0.524

Notes: *Denotes statistically significant difference between surfer and control groups ($p<0.05$, two-tailed).
Abbreviations: kg, kilograms; m, meters; std, standard; %RDI, percentage of the recommended daily intake; cBPAQ, current bone-specific physical activity questionnaire score; pBPAQ, past bone-specific physical activity questionnaire score; tBPAQ, total bone-specific physical activity questionnaire score; BMI, body mass index; BMD, bone mineral density; LS, lumbar spine; g, grams; cm, centimeter.

osteopenia (42.2% controls, 40.7% surfers), with no statistically significant difference between the groups in this regard (x_1^2 =0.025, p=0.874).

No correlations were found between the primary outcomes (femur BMD, LS BMD, and T-score) and the demographic characteristics age, calcium intake (% RDI), and number of standard drinks. Likewise, surfing-specific characteristics (surfing ability, surfing experience, number of sessions per month, number of hours per session, surfing exposure, surfing stance, and type of surfboard) were not significantly associated with the primary outcomes. The relationships between scores on the BPAQ components and the outcomes BMD and T-score are shown in Table 2. For the surfing group, significant small positive relationships were found between femur BMD and both pBPAQ and tBPAQ scores (r 0.299, $p<0.05$ and r 0.299, $p<0.05$, respectively). Additionally, significant moderate positive relationships were found between T-score and both pBPAQ and tBPAQ scores (r 0.326 $p<0.05$ and r 0.326, $p<0.05$, respectively), but not between LS BMD and any of the components of the BPAQ. There was no statistically significant correlation between cBPAQ scores and the outcomes in surfers. When both groups were analyzed in combination, significant moderate positive relationships were found between femur BMD and both pBPAQ and tBPAQ scores (r 0.386, $p<0.01$ and r 0.385, $p<0.01$, respectively), and also between T-score and both pBPAQ and tBPAQ scores (r 0.430 $p<0.01$ and r 0.436, $p<0.01$, respectively). Similarly, a small positive relationship was found between LS BMD and both pBPAQ and tBPAQ scores (r 0.209 $p<0.05$ and r 0.221, $p<0.05$, respectively). By contrast, cBPAQ scores did not correlate with the primary outcomes when all participants were analyzed together.

The control group was composed of physically active individuals. Walking was the most common exercise (15 individuals), followed by cycling (14 individuals),

Table 2 Correlations between scores from BPAQ components and the outcomes femur BMD, LS BMD, and T-score

OUTCOMES	Surfers (n=59)			Controls (n=45)			All participants (n=104)		
	cBPAQ	pBPAQ	tBPAQ	cBPAQ	pBPAQ	tBPAQ	cBPAQ	pBPAQ	tBPAQ
Femur BMD (g/cm²)	0.017	0.299*	0.299*	0.343*	0.419**	0.422**	0.170	0.386**	0.385**
LS BMD (g/cm²)	−0.051	0.167	0.167	0.296	0.307	0.329*	−0.040	0.209*	0.221*
T-score	−0.034	0.326*	0.326*	0.476**	0.433**	0.439**	0.190	0.430**	0.436**

Notes: Pearson's correlation used; *correlation is significant at the 0.05 level (two-tailed); **correlation is significant at the 0.01 level (two-tailed).
Abbreviations: BPAQ, bone-specific physical activity questionnaire; BMD, bone mineral density; LS, lumbar spine; cBPAQ, current BPAQ score; pBPAQ, past BPAQ score; tBPAQ, total BPAQ score; g, grams; cm, centimeter.

running (8 individuals), swimming (3 individuals), resistance training (3 individuals), soccer (1 individual), and triathlon (1 individual). Participants were grouped according to their main current physical activity into three groups: surfing (n=59), non-weight-bearing/low intensity (NWBLI, n=32), and weight-bearing/high intensity (WBHI, n=13) as shown in Table 3. A Chi-square test of independence was conducted to examine the relationship between type of physical activity (surfing, WBHI, and NWBLI) and diagnosis of osteopenia based on the participants' T-score. There was a statistically significant association between type of physical activity and diagnosis of osteopenia (x_1^2 =13.464, p=0.001). The association was moderately strong, Cramer's V=0.36.[23] The group NWBLI had the highest prevalence of osteopenia (59.4%) when compared to surfing (40.7%) and WBHI (0%). A one-way MANOVA was conducted to determine if the dependent variables femur BMD, LS BMD, and T-score were different for the three different types of physical activity (surfing, WBHI, and NWBLI). Descriptive statistics summarizing the results for each of the primary outcomes in the physical activity groups are shown in Table 4. There were statistically significant differences between the groups reflecting type of physical activity in the combined dependent variables (femur BMD, LS BMD, and T-score), $F(6, 188)$ =3.124, p=0.006; Pillai's Trace=0.18; partial η^2=0.091. Follow-up univariate ANOVAs showed that femur BMD ($F[2, 95]$=4.310, p=0.016; partial η^2=0.083), LS BMD ($F[2, 95]$ =3.960, p=0.022; partial η^2=0.077), and T-score ($F[2, 95]$=7.40, p=0.001; partial η^2=0.135) all differed significantly between the different physical activity groups. The primary outcomes improved from the NWBLI group to surfing, and from surfing to WBHI group, in that order.

Table 3 Participants' main current physical activity

Physical activity	N	Group
Surfing	59	Surfing (n=59)
Swimming	3	NWBLI (n=32)
Cycling	14	
Walking	15	
Resistance training	3	WBHI (n=13)
Running	8	
Soccer	1	
Triathlon	1	
Total	104	104

Abbreviations: N, number of individuals; NWBLI, non-weight-bearing/low intensity; WBHI, weight-bearing/high intensity.

Table 4 Primary outcomes by type of physical activity

Outcome	Type of physical activity	Mean	SD
Femur BMD (g/cm^2)	NWBLI	0.930	0.090
	WBHI	1.044	0.106
	Surfing	0.969	0.123
LS BMD (g/cm^2)	NWBLI	1.179	0.113
	WBHI	1.260	0.099
	Surfing	1.243	0.107
T-score	NWBLI	−1.1	0.7
	WBHI	−0.2	0.6
	Surfing	−0.7	0.8

Abbreviations: BMD, bone mineral density; LS, lumbar spine; g, grams; cm, centimeter; NWBLI, non-weight-bearing/low intensity; WBHI, weight-bearing/high intensity.

Games-Howell post-hoc tests showed that for femur BMD, the WBHI group had a significantly higher mean than the NWBLI group (MD +0.114; 95% CI 0.025–0.203; p=0.011); however, no differences were found between the WBHI and surfing groups or between the surfing and NWBLI groups. For LS BMD, surfers had a significantly higher mean than the NWBLI group (MD +0.064; 95% CI 0.002–0.126; p=0.041), but no differences were found between surfing and WBHI or between WBHI and NWBLI. Lastly, for T-score, the WBHI group had a significantly higher mean than the NWBLI group (MD +0.918; 95% CI 0.389–1.446; p=0.001) and surfing (MD +0.516; 95% CI 0.024–1.009; p=0.039), and surfers had a significantly higher mean than the NWBLI group (MD +0.401; 95% CI 0.012–0.791; p=0.042). MD and 95% CI are shown in Table 5.

Multiple regression analyses were run to predict the primary outcomes from the cBPAQ, pBPAQ, and tBPAQ scores. The components of the BPAQ statistically significantly predicted T-score ($F[3, 100]$=8.048, p<0.0005) and femur BMD ($F[3, 100]$=5.688, p=0.001), but not LS BMD (F [3, 94]=2.036, p=0.114). For T-score, the R^2 value for the overall model was 19.4% with an adjusted R^2 of 17.0%, and for femur BMD the R^2 value for the overall model was 14.6% with an adjusted R^2 of 12.0%. Predictions were made to determine an average score required for each of the components of the BPAQ in order to result in a T-score within the lower bound of the normal range. Results revealed that a cBPAQ score of 0.969, a pBPAQ score of 68.817, and a tBPAQ of 33.705

Table 5 One-way MANOVA post-hoc analyses: mean differences in outcomes between activity types

Outcomes	Types of physical activities compared		Mean difference	p-value	95% CI	
					Lower	Upper
Femur BMD (g/cm^2)	WBHI	NWBLI	0.114*	0.011	0.025	0.203
		Surfing	0.075	NS	−0.014	0.162
	Surfing	NWBLI	0.039	NS	−0.017	0.095
		WBHI	−0.075	NS	−0.163	0.014
LS BMD (g/cm^2)	WBHI	NWBLI	0.081	NS	−0.009	0.170
		Surfing	0.017	NS	−0.065	0.099
	Surfing	NWBLI	0.064*	0.041	0.002	0.126
		WBHI	−0.017	NS	−0.099	0.065
T-score	WBHI	NWBLI	0.918*	0.001	0.389	1.446
		Surfing	0.516*	0.039	0.024	1.009
	Surfing	NWBLI	0.401*	0.042	0.012	0.791
		WBHI	−0.516*	0.039	−1.009	−0.024

Notes: Based on observed means; Games-Howell post-hoc test used; *the mean difference is significant at the 0.05 level.
Abbreviations: MANOVA, multivariate analysis of variance; BMD, bone mineral density; LS, lumbar spine; g, grams; cm, centimeter; WBHI, weight-bearing/high intensity; NWBLI, non-weight-bearing/low intensity.

would result in a mean T-score of −0.7 (95% CI, −0.8 to −0.6). A hierarchical multiple regression was run to determine whether the addition of %lean mass and type of physical activity improved the prediction of the primary outcomes over and above the components of BPAQ. Neither of these additional predictors led to a statistically significant improvement in predicting femur BMD, LS BMD, or T-score ($p>0.05$).

A randomized sample of 20 individuals, 10 in each group, was selected for analysis of serum biomarkers of bone turnover (CTx and P1NP). The mean results for both groups were within normal range for both CTx and P1NP, with no significant difference between groups (Table 6).

Discussion

The primary goal of the present study was to assess the bone health of middle-aged and older male surfers and to compare the results with those from a control group comprised of age- and sex-matched active non-surfer individuals. To the best of our knowledge, this is the first study to investigate the bone health of middle-aged and older surfers by assessing the traditional clinical BMD sites (femur and LS), as recommended by the WHO[16] and ISCD.[15] The main findings of the present study support the hypothesis that surfing is associated with reduced age-related bone deterioration, as we identified positive results for surfers in relation to our primary outcomes (femur BMD, LS BMD, and T-score).

A strong relationship between exercise and bone health has been reported in the literature; however, different modalities of exercise have different effects on bone health. To date, the sport of surfing has not been adequately investigated in relation to its association with age-related bone loss. To address this gap, we recruited and compared a group of middle-aged and older surfers and a group of physically active individuals, who were non-surfers and age- and sex-matched, as controls. Demographic characteristics (Table 1) were similar

Table 6 Biochemical markers of bone turnover, mean and SD values by group

Biomarker	Surfers (n=10)		Controls (n=10)		p-value
	Mean	SD	Mean	SD	
PINP (µg/L)	47.6	20.3	49.6	13.2	0.797
CTx value (ng/L)	384	200.0	400	203.3	0.861

Notes: PINP normal range: 15–80 µg/L; CTx normal range: 100–600 ng/L.
Abbreviations: PINP, procollagen type 1 N-terminal propeptide; CTx, C-telopeptide cross-link of type 1 collagen.

between the groups, except for %lean mass and cBPAQ score. The cBPAQ score obtained from surfers was approximately one-third of the score obtained from individuals in the control group. This was expected as, consistent with our inclusion criteria, surfers included in the study could not be involved in any other type of physical activity. Additionally, surfing only receives a small score in the BPAQ, due to its relatively small peak ground reaction force. This may explain the smaller scores (although not significantly different) obtained by surfers in the pBPAQ and tBPAQ when compared to control participants, as surfing was the main physical activity for the majority of the surfers during their lifetime.

Individuals in the control group were engaged in different exercise modalities, and these activities were grouped based on their weight-bearing/intensity characteristics in two different groups: NWBLI (eg, swimming, cycling, and walking) and WBHI (eg, resistance training, running, soccer, triathlon) (Table 3). The NWBLI group had the lowest values for all three primary outcomes (Table 4). Additionally, surfers had significantly higher LS BMD and T-scores when compared to the NWBLI group; however, surfers had a lower mean T-score than the WBHI group (Table 5).

The current study found a prevalence of osteopenia of 41.3%, with no difference between surfing and control groups. This prevalence rate is lower than that previously reported for the Australian general population, which was 55% for men.[24] However, this difference is likely to be mainly due to the exclusion of men with known osteopenia or osteoporosis from the study, so they would not have responded to invitations to participate if they knew they suffered from one of these conditions and understood it was an exclusion criterion. The same guidelines reported a prevalence of 3% of osteoporosis in men; however, none of the individuals in our study met the diagnostic criteria for osteoporosis, though this again might be due to the exclusion of men with known osteoporosis from participation in the study.

There is a paucity of available literature on bone health in mature-aged male aquatic athletes and available studies do not report findings specific to osteopenia and osteoporosis.[25,26] Velez et al[3] investigated the effects of swimming on bone health in senior athletes (72.6 years ±6.8). They reported the percentage of osteopenia amongst the male swimmers ranged from 14% in the spine to 48% in the femoral neck and osteoporosis ranging from approximately 7.5% in the hip to 15% in the 1/3 distal radius. Leigey et al[27] conducted a large-scale study into the bone health of 560 senior athletes (65.9 years +8.53) participating in 18 different sports in the National Senior Games (ie, Senior Olympics). Unfortunately, these investigators used calcaneal quantitative ultrasound to assess BMD which cannot report BMD in g/cm^2 for comparison, neither did they report T-scores. However, 6.7% of the athletes (mixed sports) were deemed to be osteoporotic based upon reporting a prescribed osteoporosis specific medication.

It is nevertheless possible that the differences we observed in the prevalence of osteopenia and osteoporosis may also in part be explained by the fact that all participants in our study were currently physically active, particularly given that osteoporosis and osteopenia are often undiagnosed and some participants would conceivably not have known they had it at the time they volunteered to participate and would, therefore, still have been recruited. When results of the present study were analyzed according to the type of physical activity (ie, surfing, NWBLI, and WBHI), the surfing group had a prevalence of osteopenia of 40.7%, almost 20% lower than that for the NWBLI group ($\chi^2(2)=13.464$, $p=0.001$), and nearly 15% lower than that previously reported in the literature.[24] This difference cannot be explained by the study exclusion criteria, since all participants, in both groups, were subject to those criteria.

With regard to BPAQ scores, when all participants were analyzed in combination, pBPAQ and tBPAQ scores were correlated to the primary outcomes (Table 2); however, no association was found between the outcomes and cBPAQ scores. When only the surfing group was analyzed, there was no correlation between scores on the three components of the BPAQ and LS BMD, but there was correlation between pBPAQ and tBPAQ scores and both femur BMD (small correlation) and T-score (moderate correlation). For the control group, there was a moderate correlation between all components of the BPAQ and the primary outcomes, except for between cBPAQ and pBPAQ scores and LS BMD. Similar findings were reported by Bolam et al,[28] who analyzed a group of healthy middle-aged and older men and reported moderate correlations between scores on the three components of the BPAQ and femoral neck BMD; however, the authors did not find a significant correlation between BPAQ scores and LS BMD.

On average, surfers had over 40 years of experience in the sport, with more than 25 hrs per month of surfing exposure. These characteristics are in line with the findings of the previous study in surfers.[10] The main difference is the type of board used by the participants. In the present study, more than 54% of the individuals used a shortboard, which is associated with a more dynamic performance, whereas all surfers in the previous study were longboarders. Even though surfing characteristics were not correlated with our primary outcomes, increased neuromuscular activation, associated with muscle force production, in order to control movements and posture during the different physical demands associated with the sport, may be considered important contributors to the positive findings revealed by our analyses in the surfing group. Hwang et al[29] propose that repetitive forceful muscular contractions against the resistance of the water may have a beneficial effect on BMD. Given the surfers are paddling and then weight-bearing, this short-term, intense activity may act as a stimulus for bone development. Based on the results for the primary outcomes in the surfing group, it seems that the BPAQ may not accurately score the impact of the sport on bone health. This can be illustrated by the relatively low mean scores for the surfing group for all three components of the BPAQ (Table 1).

In the analysis of biochemical markers of bone turnover, we were able to include 20 participants in the analyses – 10 surfers and 10 controls. We failed to find a significant difference between the groups, most likely due to the small sample size, and therefore no assumptions can be made on this basis. The only previous study[10] which also investigated bone health in mature-aged male surfers also reported no significant differences with regard to CTx (0.28 µg/L ±0.076) and P1NP (45.4 µg/L ±15.9).

The main strength of this study is its eligibility criteria, allowing better control of confounding factors (eg, medical conditions and medications known to affect BMD, smoking status, calcium, and alcohol intake, very low or very high BMI) that could potentially interfere with the results. However, limitations should be highlighted. Firstly, the study design does not allow us to infer cause and effect; secondly, the sample size was small, due to the strict eligibility criteria; lastly, we did not assess vitamin D, due to budget limitations. Therefore, findings of the present study should be interpreted with caution and cannot be extrapolated to all individuals.

Conclusion

The purpose of the current study was to determine the bone health of middle-aged and older surfers. Results were compared to those for a physically active, age- and sex-matched control group. Surfers have statistically higher BMD at the LS and higher T-scores when compared to individuals engaged in non-weight-bearing/low impact physical activities. Overall, this study strengthens the idea that surfing might be an effective exercise to decrease the rate of bone loss associated with aging. A natural progression of this work is to conduct a longitudinal analysis of the bone health in this population.

Disclosure

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Appendix VIII: Ear discomfort in a competitive surfer – published version

Ear discomfort in a competitive surfer

Vini Simas, James Furness, Wayne Hing, Rodney Pope, Joe Walsh, Mike Climstein

Case

A previously healthy, competitive surfer (male, aged 23 years) from the Gold Coast presented with chronic ear discomfort, having noticed frequent water trapping in the ear canal (Figure 1). He had been surfing for 11 years and denied participating in any other form of water activity.

Question 1

What is surfer's ear?

Question 2

What is the clinical presentation of surfer's ear?

Question 3

What is the prevalence of surfer's ear in surfers?

Question 4

What are the pathophysiology and aetiology of surfer's ear?

Question 5

What are the risk factors of surfer's ear?

Question 6

How is surfer's ear diagnosed?

Question 7

What are the differential diagnoses of someone suspected of having surfer's ear?

Question 8

Is surfer's ear preventable?

Question 9

What is the treatment of surfer's ear?

Figure 1. Otoscopic image identifying auditory exostoses in a young male competitive surfer

Question 10

When is it appropriate to refer a patient with surfer's ear to a specialist?

Answer 1

Surfing is a popular recreational activity and competitive sport, with an estimated 37 million surfers worldwide.[1] In Australia, this number is estimated at 2.7 million, which accounts for more than one in 10 Australians.[2] One of the chronic conditions associated with surfing is external auditory exostosis (EAE). This condition is a benign and irreversible, broad-based bone outgrowth that arises from the temporal bone and projects into the external auditory canal (EAC). EAE is commonly referred to as surfer's ear, although it has also been described in other aquatic sports. Australia is recognised as having a high prevalence of EAE.[3–5]

Answer 2

Typically found bilaterally with multiple lesions, EAE is usually asymptomatic and hence is often diagnosed when the condition is at an advanced stage,[6] leading to a higher incidence of potentially serious health issues. Patients can present with a prolonged blocked feeling in the ears following water activities because of water trapping in the EAC or chronic cerumen impaction. Patients may also present with recurrent otitis externa, otalgia and conductive hearing impairment due to stenosis of the EAC.

EAE can be classified into four grades of severity based on the percentage of obstruction of the EAC, as assessed by otoscopy (Figure 2):[7]

- Grade 0 – normal ear canal, no visible exostosis
- Grade 1 – obstruction of up to 33%
- Grade 2 – obstruction of 34–66%
- Grade 3 – obstruction of 67–100%.

Answer 3

The prevalence of this condition in surfers, both professional and recreational, is 38–80% when investigated by otological examination.[8,9] A study in Victoria reported that 78% of male surfers and 69% of female surfers had some degree of exostoses; a severe grade (ie Grade 3) was observed in more than 50% of the male surfers diagnosed.[3] However, our recent study investigating injuries while surfing via an online survey identified only 3.5% of the participants reporting exostoses.[10]

Answer 4

The precise mechanism for the development of EAE remains unknown. Cold water and air exposure are believed

Figure 2. Otoscopic image identifying the four grades of EAE
Grades 1–3 reproduced from Nakanishi H, Tono T, Kawano H. Incidence of external auditory canal exostoses in competitive surfers in Japan. Otolaryngol Head Neck Surg 2011;145(1):80–85 with permission from SAGE Publications, Inc.

to stimulate osteoblasts within the temporal bone, leading to bone growth into the EAC, possibly as a mechanism to protect the tympanic membrane against low temperatures.[11,12]

Answer 5

It is well known that EAE is highly correlated with the amount of time spent in the water. The risk of EAE increases after five sessions of surfing per month and significantly increases after five years of surfing.[13,14] Exposure to cold water and wind are recognised risk factors.[15,16] With regard to the wind effect, it has been proposed that evaporative cooling would result in greater progression of exostoses in the ear more exposed to a predominant wind. However, some studies did not find significant differences in prevalence and severity between the ears, even though one ear was typically more exposed to the wind than the other.[12] Exostosis of the EAC does not appear to be influenced by genetic factors or any type of medication.[12,17]

Answer 6

Auditory exostosis is diagnosed via otoscopic examination to identify bony outgrowths projecting into the EAC.

Answer 7

Some of the differential diagnoses of EAE include osteoma, squamous cell/glandular cell carcinoma, benign glandular tumours, cholesteatoma and conditions affecting the temporal bone (eg paraganglioma).[18]

Answer 8

The feasibility of EAE prevention remains uninvestigated. However, given the current theory of aetiology, the regular use of earplugs or other protective equipment (eg hood) has been suggested in the literature to prevent the occurrence of EAE.[14] Avoiding exposure to cold or windy conditions when surfing is also recommended.

Answer 9

The definitive treatment of EAE is surgical removal, which is usually only reserved for severe and symptomatic cases. This procedure does not prevent recurrence and exposes the individual to risk of complications, such as tympanic membrane rupture, sensorineural hearing loss, facial nerve injury, infection, delayed healing and stenosis.[4,15]

Answer 10

Referral to an otorhinolaryngologist is advised for large lesions (Grade 3), recurrent ear infections or progressive hearing loss. Referral is also recommended if the doctor or patient have any concerns, and when there is suspicion of another diagnosis (eg tumour) or when the symptoms are not compatible with clinical findings (eg hearing loss with only a small lesion). An audiogram should be organised prior to referral.[18]

Key points

- EAE is a common condition in surfers.
- EAE is typically undiagnosed at early stages.
- EAE is a potentially serious health issue.
- Risk factors of EAE include exposure to cold water and wind.
- The only treatment for EAE is surgical correction, which is reserved for severe or symptomatic cases.
- Prevention of EAE should be highlighted, and general practitioners play an important role in early identification and advising susceptible patients.

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Appendix IX: The Prevalence and Severity of External Auditory Exostosis in Young to Quadragenarian-Aged Warm-Water Surfers: A Preliminary Study – published version

sports

MDPI

Article

The Prevalence and Severity of External Auditory Exostosis in Young to Quadragenarian-Aged Warm-Water Surfers: A Preliminary Study

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Abstract: External auditory exostosis (EAE) has previously only been shown to occur in cold water surfers. We assessed young surfers living and surfing in Queensland, Australia, for EAE in water temp ranges from 20.6 °C (69.1 °F, Winter) to 28.2 °C (82.8 °F, Summer). All participants underwent a bilateral otoscopic examination to assess the presence and severity of EAE. A total of 23 surfers participated with a mean age of 35.4 years (8.3 years) and a mean surfing experience of 20.0 years (9.9 years). Nearly two-thirds of participants (n = 14, 60.9%) had regular otological symptoms, most commonly water trapping (n = 13, 56.5%), pain (n = 8, 34.8%), and hearing loss (n = 6, 26.1%). Only 8.7% (n = 2) of all surfers reported regular use of protective equipment (e.g., earplugs) on a regular basis. The overall prevalence of exostosis was 69.6% (n = 16), and the majority (n = 12, 80.0%) demonstrated bilateral lesions of a mild grade (<33% obstruction of the external auditory canal). This is the first study assessing EAE in young surfers exposed to only warm waters (above 20.6 °C). The prevalence of EAE in this study highlights that EAE is not restricted to cold water conditions, as previously believed. Warm water surfing enthusiasts should be screened on a regular basis by their general medical practitioner and utilize prevention strategies such as earplugs to minimize exposure to EAE development.

Keywords: auditory exostoses; surfing; surfer's ear; otology; preventive medicine; sports medicine

1. Introduction

It is estimated that there are approximately 35 million surfers worldwide, with 2.7 million in Australia [1]. Given that surfing has been added as a new sport in the 2020 Tokyo Olympics [2] and the development of wave pools, the popularity of this aquatic activity is expected to increase dramatically over the coming years. There have been numerous studies (prospective, retrospective) that have investigated injuries (acute and/or chronic) in recreational and/or competitive surfers, with data attained from online surveys, emergency departments, and medical records [3–13].

Despite the focus of these studies on musculoskeletal injuries and their mechanisms, location, and severity, there have been limited studies on one particular chronic injury, that being external auditory exostosis. Exostosis is colloquially known as surfer's ear and generally occurs bilaterally [6]. Exostosis is a non-life-threatening medical condition that is benign, irreversible, and believed to be reactive bony outgrowths which develop from the temporal bone from exposure to cold water [14–17]. The exact mechanism for exostosis is unknown; however, it is widely believed that cold water and cold air stimulate osteoblasts within the temporal bone of the ear and, subsequently, this results in the bony growths providing as a protective mechanism to the tympanic membrane against cold water and cold air [16,18].

Individuals with exostosis may experience water trapping, otitis externa (inflammation of the ear canal), otalgia (earache), and hearing impairment due to the stenosis of the external auditory canal (EAC). Exostosis is classified via otoscopic examination into three grades of severity based upon the percentage of occlusion of the EAC (Figure 1). Grade "1" occludes the EAC by 1% to 33%, Grade "2" occludes the EAC by 34% to 66%, and Grade "3" occludes the EAC by 67% to full occlusion (i.e., 100%) [19]. The only treatment for severe (i.e., Grade 3 and/or highly symptomatic) exostosis remains surgical removal; however, this procedure exposes the surfer to complications which can include tympanic membrane rupture, hearing loss, facial nerve injury and infection [20,21].

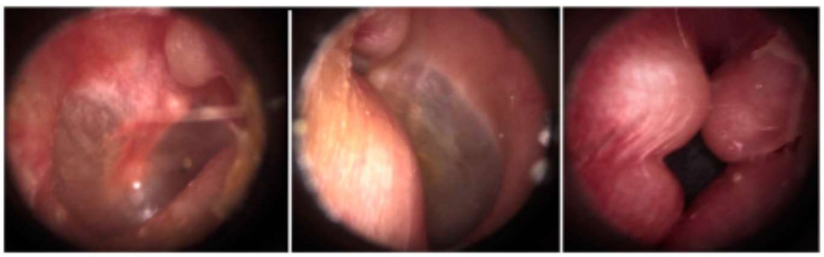

Figure 1. Otoscopic images identifying the grades of exostosis.

Van Gilse [22] was one of the first researchers to report exostosis in cold water swimmers, and shortly thereafter, Fowler and Osmon [23] reported that water temperatures of 17.5 °C resulted in the development of exostosis lesions. The cold water hypothesis was further supported when Kennedy [24] compared coastal populations of surfers and reported that exostosis was more commonly seen in colder waters.

The lifetime prevalence of exostosis in surfers has been reported, ranging from 38% in East Coast US surfers [14] to 80% in Japanese surfers [15] when investigated by otological examination. Hurst [25] reported a lifetime prevalence of 78% in male surfers and 69% in female Victoria (Australia) surfers, with more than fifty percent exhibiting Grade 3 severity. We previously investigated the lifetime prevalence of exostosis in Australian surfers via survey, however, identified only a 3.5% prevalence [26]. At present, there is only one study to date that has investigated the lifetime prevalence of exostosis in warm-water surfers (or swimmers). Kroon and colleagues [14] reported a warm-water prevalence of 15.3% in the East Coast Surfing Championship competitors (Virginia Beach, Virginia); however, the authors defined warm water as a temperature of 16.1 °C (61 °F), and this is below 19 °C, a cut-off temperature that has been previously suggested in the literature [24].

In South-East Queensland (Australia), our local ocean temperature ranges from a minimum of 20.6 °C (69.1 °F) in winter to 28.2 °C (82.8 °F) in summer [27]. Given the popularity of surfing in the local region, we sought to investigate if warm-water only surfers demonstrated exostosis and, if so, determine the severity via otoscopic examination.

2. Materials and Methods

We conducted a cross-sectional investigative study where we attempted to recruit 50 surfers aged 18 to 45 years who primarily surfed in the Gold Coast area of Queensland (Australia) (Bond University Human Research Ethics Committee approval number RO15221).

2.1. Participants

Participants were required to have surfed year-round with a minimum of five years of current surfing exposure with a minimum of 5 surfing sessions per month. Surfers with ≥ 3 weeks of cold exposure (surfing, swimming, skiing, snowboarding) or a recent history of otological surgery were excluded from participation in this study.

Twenty-three surfers (19 males, 4 females) aged 18 to 45 years (mean age 35.4 SD 8.3 years), who almost exclusively surfed in the Gold Coast area (1 participant surfed in Hawaii (USA) and Bali (Indonesia), both of which have warmer water than the Gold Coast winter ocean temperature), volunteered to participate in this study.

2.2. Testing Procedures

Upon arrival at the Water Based Research Unit, participants were provided an information sheet about the study and questions pertaining to the study and its methodologies were answered at this time. Participants then signed informed consent. Next, all participants completed a short questionnaire about their surfing demographics and medical history specific to their ears (i.e., history of exostosis, otitis externa, otalgia, water trapping, and hearing loss). Hearing loss was a subjective symptom when reported by participants; no audiological testing was conducted to quantify this symptom.

Following the completion of the questionnaire, all participants underwent bilateral otoscopic examination with a digital otoscope attached to a laptop computer (Digital MacroView™, halogen HPX fiber-optic otoscope, Welch Allyn®, Skaneateles Falls, NY, USA). This device provided live images on the computer, which were later saved digitally in JPEG file format.

Whilst participants were undergoing the otoscopic examination, they were advised if exostosis/exostoses were present and, if so, the severity based upon the one to three scale [19] (Figure 1). All participants received educational information about the disorder and common potential preventative measures (i.e., earplugs, drops).

2.3. Statistical Analyses

The normality of all data was assessed by investigating kurtosis, skewness, Q-Q plots, and the Shapiro–Wilk test. Heteroscedasticity was also assessed using Levene's test for the equality of variances. Where outcome variables were categorical, results were summarized as frequencies and percentages (absolute). Data are presented as mean (SD) or percentage throughout unless noted. A bivariate Spearman rank-order correlation was utilized to assess the associations between age, years surfing, and winter surf exposure and the severity of exostosis. Statistical analyses were competed using IBM SPSS Statistics for Windows statistical software (Version 25.0, IBM Corp., Armonk, NY, USA).

The required minimum sample size for adequate study power was computed. This analysis was conducted for a study design comparing the study group to a population incidence based on a dichotomous/binomial endpoint (exostosis or no exostosis). With the variables utilized to calculate minimum sample size set at alpha = 0.05, power = 80% (giving beta of 20%), and an anticipated population incidence of 38% (the lowest reported incidence in the literature in otoscopic studies), the minimum sample size for adequate study power was calculated at 10 subjects (5).

3. Results

There were no significant differences between genders; males were slightly older than females (8.1%) and reported more years surfing (35.6%). Six of the participants also swam, two participated in stand-up paddle boarding, and two participants participated kite surfing in the Gold Coast area. Participants had been surfing for an average of 20.0 years (range 6 to 42) and had skill levels (according to the Hutt scale [28]) from beginner (4.3%) to top amateur (21.7%, able to consecutively execute advanced maneuvers). The majority (95.7%) were riding short boards. The participant demographics are listed in Table 1.

Table 1. Participant's demographics (vales are mean SD or percentage).

Parameter	Group (n = 23)	Males (n = 19)	Females (n = 4)	*p* Value
Age (years)	35.4 (8.3)	35.9 (7.5)	33.0 (12.7)	0.06
Surfing experience (years)	20.4 (9.9)	21.4 (8.23)	13.8 (10.9)	0.17
Winter surfing sessions (number)	14.0 (8.3)	12.9 (8.3)	19.0 (6.8)	0.19
Winter surfing sessions (hours/session)	1.7 (0.6)	1.8 (0.7)	1.6 (0.3)	0.11
Surfing stance:				
• Regular (left leg forward, %)	87.0	84.2	25.0	–
• Goofy (right leg forward, %)	13.0	15.8	75.0	–
Board type:				–
• Short board (%)	95.7	100.0	75.0	
• Long board (%)	4.3	0.0	25.0	

Regarding the diagnosis of exostosis, participants were identified with an overall lifetime prevalence of 69.6% of exostosis (three females and 13 males). When we evaluated the lifetime prevalence of exostosis, the youngest participant identified was a female of 27 years of age. The youngest quartile (≤31 years) relative lifetime prevalence was 33.3%, the 2nd quartile (aged 32 to ≤37 years) relative lifetime prevalence was 83.3%, the 3rd quartile (aged 38 to < 41 years) was 80.0%, and the oldest quartile (≥42 years) had a relative lifetime prevalence of 83.3% (Figure 2). Of those diagnosed with exostosis, the majority (80.0%) demonstrated bilateral exostosis (i.e., exostosis was identified in both the right and left ear) with a severity of Grade 1 (30.4%) (Table 2).

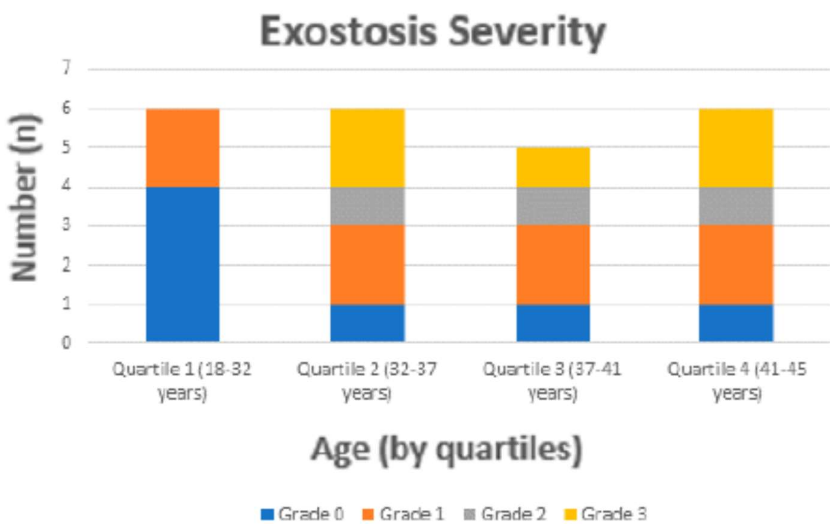

Figure 2. Exostosis severity by age quartile.

There was a significant correlation between age and the severity of exostosis for both ears (right $r^2 = 0.428$, $p = 0.042$; left $r^2 = 0.606$, $p = 0.002$) and years surfing and severity of exostosis for both ears (right $r^2 = 0.538$, $p = 0.08$; left $r^2 = 0.613$, $p = 0.003$). Additionally, there was a significant ($p = 0.003$) positive correlation between the severity of exostosis in the right ear and the severity of exostosis in the left ear ($r^2 = 0.591$, $p = 0.001$), There was, however, no significant correlation between winter surf exposure and the right and left ear exostosis severity ($r^2 = 0.231$, $p = 0.588$; $r^2 = 0.176$, $p = 0.987$, respectively).

Approximately two thirds of participants (60.9%; male = 11, female = 3) reported experiencing regular otological symptoms, the most common of which was water trapping (56%; male = 11, female = 2), pain (34.8%; male = 6, female = 2), and hearing loss (26.1%; male = 4, female = 2).

With regard to exostosis prevention, the majority (69.6%) were aware of prevention methods, however, only approximately one-third (34.8%; males = 6, females = 2) actually reported utilizing any form of prevention for exostosis. The most commonly reported prevention method was earplugs (26.1%) followed by Blu-tack® and a combination of earplugs and ear drops (4.3% each).

Table 2. Participant's demographics with regard to exostosis (values are mean SD or percentage).

Parameter	Group (n = 23)	Males (n = 19)	Females (n = 4)
Exostosis identified (%)	69.6	68.4	75.0
Exostosis by Age Quartile (%)			
• ≤ 31 years	66.70	75.0	50.0
• 32 to ≤ 37 years	83.3	83.3	0.0
• 38 to ≤ 41 years	80.0	80.0	0.0
• ≥ 42 years	83.3	83.3	100.0
Exostosis Severity (1 to 3)			
• no visable exostosis (%)	41.3	42.1	16.7
• Grade 1 (%)	30.4	26.3	66.7
• Grade 2 (%)	10.9	10.5	16.7
• Grade 3 (%)	17.4	21.1	0.0
Exostosis Bilateral			
• Yes (%)	80.0	76.9	100.0
Exostosis location and severity			
• Right ear	52.2	52.6	50.0
Grade 1 (%)	41.7	30.0	100.0
Grade 2 (%)	25.0	30.0	0.0
Grade 3 (%)	33.3	40.0	0.0
• Left ear	65.2	63.2	75.0
Grade 1 (%)	60.0	58.3	66.7
Grade 2 (%)	13.3	8.3	33.3
Grade 3 (%)	26.7	33.3	0.0

4. Discussion

The primary purpose of this study was to determine if exostosis, which was previously believed to be limited to cold-water only surfers, existed in warm water Australian surfers and, if so, determine the severity via otoscopic examination. Our main finding indicated that exostosis is indeed present in warm-water surfers, and its lifetime prevalence in our participants was similar to that previously reported in cold water surfers [15].

4.1. Lifetime Prevalence of Exostosis

We identified a lifetime prevalence of exostosis of approximately 70% in our cohort of participants, which were warm-water surfers in South-East Queensland (Australia, winter temperature ranged from 20.6 °C (69.1 °F) to 28.2 °C (82.8 °F) in summer). These findings are similar to those reported in cold-water surfers by Umeda et al. [15], who identified a prevalence of 80% exostosis in Japanese surfers and findings similar to Hurst and colleagues [25], who reported a prevalence of exostosis of 75% in male surfers and 69% in females surfers in Victoria, Australia (13.6 °C in Winter to 20.3 °C in summer) [27]. Our findings are also similar to Attlmayr and Smith [16], who reported a prevalence of 63.8% in Cornish surfers (water temperature 8.4 °C in winter to 19.3 °C in summer) [27]. Chaplin and Stewart [29] investigated the prevalence of exostoses in New Zealand surfers (n = 54) and surf life savers (n = 38) in Dunedin (water temperature 10.0 °C in winter to 14.0 °C in summer) and reported an overall prevalence of 73.0%. Additionally, all surfers with 10 years or more surfing experience had some evidence of exostosis.

It is interesting to note that when we evaluated exostosis via survey, as opposed to otoscopic examination, we found a lifetime prevalence of only 3.5% in Australian surfers [26] and more recently [30] 28.9% in New Zealand surfers. Chaplin and Stewart [29] reported a lifetime prevalence of exostosis of 73.0% in New Zealand surfers, with one half presenting with a Grade 2 or Grade 3 severity. We therefore believe that otoscopic examination is required to determine the presence (and severity) of exostosis.

4.2. Exostosis in Other Aquatic Activities

Although exostosis appears to be well investigated in surfers, exostosis has also been reported in other aquatic activities, such as diving [31–34], swimming [35–37], and kayaking [38,39]. Exostosis has been reported in divers to have a prevalence ranging from 26% in US navy divers [32] to 85.7% in Japanese Matsu divers [31]. Swimmers and kayakers (69.5% to 79%) appear to have a similar prevalence of exostosis.

With regard to investigating the prevalence of exostosis in warm water, Kroon et al. [14] is the only study that reported the prevalence of exostosis in warm-water surfers (lifetime prevalence 31%); however, they used a warm-water temperature of 16.1 °C (61 °F). Our study's ocean temperatures were 28.0% warmer in winter (20.6 °C, 69.1 °F) and considerably warmer in summer (28.2 °C, 82.8 °F). We believe that this is a better reflection of warm water, based on an anthropological study where the temperature of 19 °C (66.2 °F) was suggested as a cut-off point [24]. However, Deleyiannis et al., [17] did postulate that Californian surfers in warmer waters may simply require more time (i.e., exposure) for exostosis to occur.

This study is the first to identify exostosis in warm water, and as such, the mechanism for exostosis is unknown. Previously, it was believed that cold water and cold air stimulated osteoblasts within the temporal bone of the ear and, as a result, bony growths developed as a protective mechanism. However, based on our high prevalence of exostosis in warm-water surfers, the threshold of water and air temperature to stimulate the bony outgrowths appears to be warmer than previously believed. Deleyiannis and colleagues [17] postulated that surfers in warmer water may just require a longer period of exposure to develop exostosis. The critical temperature for the development of exostosis, however, is yet to be determined.

With regard to gender and lifetime prevalence of exostosis, 68.4% of all male participants and 100% of all female participants demonstrated exostosis. These values are similar to that previously reported by Hurst and colleagues [25] in cold-water surfers in Victoria (Australia). Participants from our youngest (18 years) to our oldest (45 years) demonstrated exostosis.

We reported a significant correlation between years surfing and the severity of exostosis; this is in agreement with Attlmayr and Smith [16], who investigated the prevalence and severity of exostosis in Cornish surfers and also identified a significant positive correlation. Attlmayr and Smith [16], however, also reported a significant correlation between the severity of exostosis and cold-water exposure, whereas we found no relationship between Winter surf exposure and the severity of exostosis.

Despite the high prevalence of exostosis in surfers, we could not identify any study that evaluated the effectiveness of protection strategies for exostosis. Timofeev and colleagues [40], in their surgical follow-up of patients with exostosis, reported that wearing earplugs prolonged the recurrence-free time period by a factor of five compared with no ear protection. Chaplin and Stewart [29] reported no difference in the severity of exostosis in cold water surfers that wore protective earplugs versus those who did not. They also commented that there was no difference in the severity of exostosis in those surfers who used either a chemical drying agent in their ears and those that did not. However, further work is required to determine the long-term efficacy of prevention strategies for exostosis.

With regard to otological symptoms, a number of studies did not report otological symptoms [14,17,41] or specifics [29,42]. Nakanishi et al. [43] found that the most common otological symptom was water trapping, and this occurred more frequently in surfers with grade 2 or more severe exostosis. They did report that there was no correlation between the severity of exostosis and other symptoms, and hearing loss was not an accompanying symptom even in grade 3 exostosis. Attlmayr and Smith [16] found that approximately one-third of their subjects reported recurrent ear infections or otalgia and the presence of symptoms increased significantly with the severity of exostosis.

Our principal strengths to this study were our methodology and inclusion criteria. Regarding methodology, we utilized a digital otoscopic attached to a notebook portable computer. The otoscope is the gold standard [19] for identifying if exostosis was present and, if so, to determine its severity. Additionally, the otoscope was connected to a laptop computer with high-resolution screen, which assisted the investigator, an experienced Sports Medicine and emergency medicine physician, with detailed analysis of identifying the presence of exostosis and quantifying its severity. Our inclusion criteria for defining warm-water surfers was quite stringent and allowed us to reduce possible confounding variables on the development of exostosis.

The primary limitation to this study was its small sample size (n = 23). Although we initially (a priori) computed the sample size numbers required, the small sample size limits the generalizability of our findings. Our stringent inclusion criteria also limited our ability to attain a larger sample size. Additionally, the limited geographic area in which we attained our sample makes generalizability limited. Although we identified exostosis in warm-water surfers, warmer water (i.e., further north in Australia, Indonesia, Fiji, Caribbean, etc.) may or may not be a sufficient stimulus to result in exostosis. This is yet to be investigated and represents an area for future research.

5. Conclusions

This study is the first to identify the lifetime prevalence of external auditory exostosis in exclusively warm-water surfers and found the prevalence to be similar to cold-water surfers. These findings have a significant health impact, as there are significantly more surfers now vulnerable to the development of exostosis. Warm-water surfing enthusiasts should, therefore, be screened on a regular basis by their general medical practitioner and utilize prevention strategies, such as earplugs, to minimize exposure to external auditory exostosis (EAE) development. Given the increased susceptibility to EAC, there is a need for research into the efficacy of proposed preventative strategies.

Author Contributions: Conceptualization, M.C., V.S. and J.F.; Methodology, V.S., M.C., J.F.; Data collection, V.S.; Data analyses, J.W. and M.C.; Writing—original draft preparation, M.C., V.S., J.W., J.F., and W.H.; Writing—review and editing, M.C., V.S., J.W., J.F. and W.H. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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Appendix X: Lifetime Prevalence of Exostoses in New Zealand Surfers – published version

ORIGINAL SCIENTIFIC PAPER
ORIGINAL RESEARCH: CLINICAL

Lifetime prevalence of exostoses in New Zealand surfers

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ABSTRACT

INTRODUCTION: External auditory exostosis (EAE) is a benign, irreversible bony outgrowth that arises from the temporal bone. EAE projects into the external ear canal, potentially causing recurrent otitis externa and conductive hearing loss.

AIM: To determine lifetime prevalence of EAE in New Zealand (NZ) surfers.

METHODS: This study used an online national survey.

RESULTS: Respondents were 1376 NZ surfers (recreational = 868, competitive = 508). Mean surfing experience was 16.2 years. Most self-classified as advanced surfers (36.5%), followed by intermediate (30.2%), expert (20.1%) and beginner (13.2%). Surfers reported an average of 214.2 h surfing (28.6% during winter) for the previous year. Overall lifetime prevalence of EAE was 28.9% (32.1% male, 14.6% female $P < 0.001$), with the highest proportion of EAE was observed bilaterally (21.3%). Competitive surfers reported a significantly ($P < 0.001$) higher lifetime prevalence of EAE than recreational surfers (45.3% vs. 19.2%). A significantly higher ($P < 0.001$) lifetime prevalence of EAE was identified as skill level increased (7.1% in beginners to 55.6% in experts) and a two-fold increase ($P < 0.001$) of EAE in the highest (vs. lowest) quartile of surfing exposure. Neither winter surfing exposure nor which Island surfed were associated with EAE prevalence.

DISCUSSION: Although not as prevalent as in previous NZ research using otologic examinations, this study indicated that almost one-third of NZ surfers reported having had a diagnosis of EAE. Regular general practitioner otologic assessment and advice on appropriate prevention strategies for patients who surf may help prevent large lesions, recurrent ear infections and progressive hearing loss.

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Introduction

External auditory exostosis (EAE), also known as Surfers Ear, is an abnormal broad-based projection of the temporal bone into the external auditory canal (EAC).[1] Although benign and usually asymptomatic, it is an irreversible condition that can lead to potentially serious complications. Commonly found bilaterally, with multiple lesions, patients can present with chronic cerumen impaction, recurrent otitis externa, otalgia and conductive hearing

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WHAT GAP THIS FILLS

What is already known: External auditory exostosis (EAE) is a reactive process that has been documented in surfers in Australia, Japan, Ireland, USA and the UK who were repeatedly exposed to water temperatures below 19°C. New Zealand (NZ) water temperatures range from 9.5°C to 21°C depending on latitude and season. Therefore, NZ surfers are likely to be susceptible to EAE.

What this study adds: This research identified a 29% lifetime prevalence of EAE in NZ recreational and competitive surfers, highlighting the importance of regular otologic screening by general practitioners of patients who surf to identify EAE in the early stages and promote preventive care measures.

impairment due to stenosis of the EAC.[2] When assessed by otoscopy, the prevalence of EAE in surfing populations ranges from 38% to 80%.[2,3]

Surgical removal is the only treatment of auditory exostosis.[1] However, the procedure does not prevent recurrence, is technically challenging and associated with complications such as hearing loss, tympanic membrane rupture, damage to the facial nerve and stenosis of the EAC.[4,5] Therefore, surgery is usually reserved for patients with severe and symptomatic lesions. Prevention of EAE remains insufficiently investigated. However, regular use of protective equipment, such as earplugs, hood or swim cap, is recommended to assist in preventing the occurrence of auditory exostoses.[6,7]

The precise mechanism for the development of EAE is not fully understood. However, it is believed that cold conditions stimulate osteoblastic activity, leading to exostoses development.[8,9] Consequently, exposure to cold water and wind are recognised risk factors affecting EAE prevalence and severity. Additionally, EAE incidence is correlated with the amount of time spent in the water, with risk increasing after five sessions of surfing per month, and significantly increasing after 5 years of surfing.[10,11]

Sea water surface temperatures in New Zealand (NZ) range from 9.5°C to 21°C depending on latitude and time of the year, with annual mean temperatures of ~15 – 17°C north of the Wellington region, 13 – 14°C in Wellington, Canterbury and Westland, and 12°C in Otago and Southland.[12,14] This temperature range has been associated with high prevalence of exostoses.[9,15,16] However, in NZ, only one study, published in 1998, has investigated the epidemiology of EAE.[17] The research was conducted in 1994 and objectively assessed 92 amateur surfers and surf lifesavers via otoscope, in Dunedin (Otago region) an EAE prevalence of 73% was reported.

Currently, it is estimated that nearly 315,000 people aged >15 years surf in NZ,[18,19] a participation rate that has doubled since the study by Chaplin and Stewart[17] was published.[20] The occurrence of EAE is a concern, and given the adverse effects of EAE and the limited data on its prevalence, further research on its prevalence in NZ surfers is warranted. Therefore, the aim of this study was to determine the lifetime prevalence of EAE in NZ surfers.

Methods

We conducted a national web-based, descriptive cross-sectional epidemiological study of NZ recreational and competitive surfers. An online questionnaire was created and distributed using a web-based application (SurveyMonkey, Palo Alto, CA, USA). The questionnaire was modified from a previous study of Australian surfers[21] and included two sections. Section 1 included questions about gender, age, years of surfing, participation type (recreational surfers were defined as surfers who had never participated in a competition and competitive surfers as surfers who had competed at local, national or international levels) and surfing exposure (hours surfed per week during summer and winter). Additionally, surfing skill level was determined using a modified version of the Hutt Scale.[22] Section 2 included questions related to surfing injuries (traumatic and gradual onset), as well as questions pertaining to history of unilateral or bilateral EAE diagnosed by their doctor.

Survey questions consisted of single choice, multiple choice, dropdown list, numerical input and short answer free text. Filters and this array of questions were used to abbreviate response times and minimise incomplete responses.

The study was promoted via newspaper articles, surf report websites, social media (free and paid advertisements) and through board-rider clubs and community notice boards. Participants in the study defined themselves as surfers currently in NZ. Only respondents who had more than 12 months' surfing experience were included in the analysis.

The study was approved by the Unitec Research Ethics Committee in accordance with the ethical standard of the Helsinki Declaration (UREC 20151032).

Statistical analyses

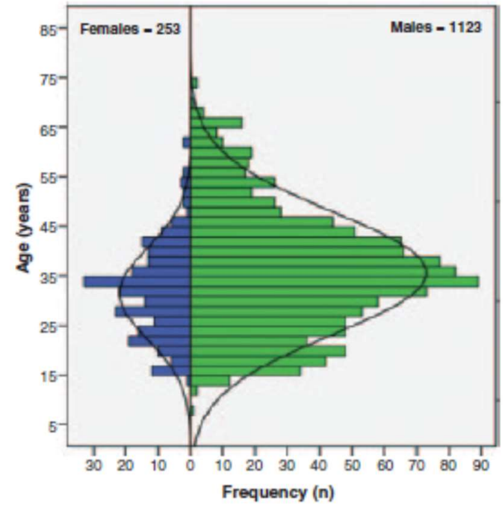
Data were initially analysed descriptively with means ± standard deviations (s.d.), count (n) or percent (%). Normality of all data were assessed by investigating kurtosis, skewness, QQ plots, as well as the Kolmogorov Smirnov test with the Lilliefors significance correction. Heteroscedasticity was also assessed using Levenes test for the equality of variances. Statistical significance of differences between genders was determined using independent samples t-tests with α set (*a priori*) to $P < 0.05$. A Pearsons correlation was utilised (where appropriate) to determine relationships. Chi-square tests and binomial logistic regression were also conducted where appropriate. All data analyses were completed using SPSS (Ver 24.0, SPSS Inc., Chicago, IL, USA).

Results

A total of 1473 participants completed the questionnaire, of whom 1376 (93.4%) completed the exostoses questions and are reported in this study. Most respondents (~95%) completed the questionnaire online, and others completed it face-to-face with one of the researchers at popular surf breaks. Most participants currently resided in NZ (for at least 6 of the previous 12 months). Of all participants, most mainly surfed in the North Island (86%), with almost one-third surfing mostly in the Auckland region (31%). The most commonly identified ethnic group(s) were NZ European (85% of participants) and Māori (12%).

Participant ages ranged from 8 to 74 years: males 8 – 74 years (n = 1123), females 13 – 62 years (n = 253) (Fig. 1).

Figure 1. Population pyramid of participants (line of normality indicated).



Median surfing experience was 13 years (interquartile range (IQR) 8 – 28 years), with most (57.1%) classified as advanced or expert surfers. They spent a median 130 h surfing (IQR 55 – 276 h), with 28% of these hours happening during winter in the previous 12 months. Table 1 shows participant characteristics by gender.

The lifetime prevalence of EAE in the surfers (recreational and competitive) was 28.9%, with males having a significantly higher ($P < 0.001$) lifetime prevalence than females (Table 2). The youngest surfer to report having EAE was a 13-year-old female, who started surfing at the age of 5 years. Mostly, reported EAE was bilateral (73.8% of EAE cases, $P < 0.001$), with no statistically significant difference in prevalence between left and right ears (Table 2).

Competitive surfers reported a significantly higher lifetime prevalence of EAE than recreational surfers (45.3% vs. 19.2%, $P = 0.001$). We identified a significantly higher lifetime prevalence of EAE as skill level increased (7.1% in beginners, 14.5% in intermediate surfers, 33.6% in advanced surfers and 55.6% in experts $P < 0.001$). When we evaluated the highest and lowest quartiles of surfing exposure (>276 h per

Table 1. Demographics of participants

Variable	Total (n = 1376)	Males (n = 1123)	Females (n = 253)
Age (years)	34.9 ± 11.8	35.7 ± 12.3	31.5 ± 9.2 **
Weight (kg)	78.0 ± 14.0	81.5 ± 12.5	62.7 ± 8.9 **
BMI (kg/m²)	24.8 ± 4.3	25.2 ± 4.1	22.8 ± 4.3 **
Surfing experience (years)	16.2 ± 11.2	17.8 ± 11.2	9.3 ± 8.3 **
Surfing location • North Island • South Island	 85.8 13.2	 85.3 13.7	 88.1 10.7
Surfing status (n) • Recreational • Competitive	 63.1 36.9	 60.9 39.1	** 72.7 27.3
Surfing level • Beginner • Intermediate • Advanced • Expert	 13.4 29.5 37.0 20.1	 7.5 26.5 42.2 23.8	** 39.5 42.7 13.8 4.0
Total surfing (h/year)	214 ± 250	226 ± 254	163 ± 228 **
Percent surfing in winter (%/year)	28.6 ± 18.7	29.8 ± 18.1	23.2 ± 20.2 **

Values are presented as mean (± standard deviation).
BMI (body mass index)
*P < 0.05; **P < 0.001 for between-gender difference.

Table 2. Lifetime prevalence of exostoses

Variable	Total (n = 1376)	Males (n = 1123)	Females (n = 253)
Exostoses	397 (28.9)	360 (32.1)	37 (14.6)**
Bilateral exostoses	293 (21.3)	270 (24.0)	23 (9.1)
Unilateral exostoses • Left ear • Right ear	104 (7.6) 47 (3.4) 57 (4.1)	90 (8.0) 42 (3.7) 48 (4.3)	14 (5.5) 5 (2.0) 9 (3.6)

Values are presented as n (%).
** P < 0.001 for between-gender difference (exostoses only).

year and 5.15 h per year), we found a two-fold higher lifetime prevalence of EAE in the highest quartile compared to the lowest quartile (119 surfers, 34.5%, vs. 60 surfers, 17.4% $P < 0.001$). Because cold water exposure might influence EAE, we also compared the lifetime prevalence of EAE between highest and lowest quartiles of winter surfing exposure and between North and South Islands. Small differences in EAE prevalence between highest and lowest quartile of winter surfing exposure (34.2% vs. 25.0%, $P = 0.2$) and North and South Island (28.5% vs. 30.9%, $P = 0.7$) did not attain statistical significance.

Seventy-seven per cent of the surfers reported surfing for >5 years, and this group had a significantly higher ($P < 0.001$) prevalence of EAE (35.3%) than surfers with <5 years' experience. Binomial logistic regression was performed to ascertain the effects of surfing for >5 years on the prevalence of EAE. The logistic regression model was statistically significant, $\chi 2 = 119.051$, $P < 0.001$, and correctly classified 71.3% of cases. Participants who surfed for >5 years had 7.4-fold higher odds of reporting exostosis than surfers who had not surfed for this length of time. Table 2 shows our findings with regard to exostoses reported by participants.

Discussion

The aim of this study was to identify the lifetime prevalence of EAE in NZ surfers. We surveyed 1376 surfers and, to the best of our knowledge, it is the largest cohort to date to be screened for EAE in NZ and the most representative of the NZ surfing population. The Māori proportion of surfers was only slightly less than the Māori proportion (15%) reported in the 2013 NZ Census.[23] Our findings revealed a prevalence of 28.9%, with nearly three-quarters of affected surfers reporting the condition bilaterally. This suggests that EAE has the potential to affect nearly 100,000 surfers in the country. This number is likely to rise, due to the increasing popularity of surfing in NZ, which is mainly attributed to the countrys coastline, allowing easy access to a range of good-quality surf breaks.[24]

Described since the 1800s,[25] EAE has been associated with water sports from the early stages of its investigation.[26] In an anthropological study,[27] the condition was found to be more prevalent in populations who depended on aquatic resources and lived between the latitudes of 30° and 45° North and South, where the annual mean water temperature is below 19°C. NZ is geographically located below the latitude of 30° south, with most of the country's coastline situated between 35° and 45°.[28] The highest annual mean surface water temperatures is ~17°C, measured in sites in Auckland and

Northland, in the North Island.[13] Therefore, NZ surfers are exposed to conditions conducive for the development of EAE.

The first study of the prevalence of EAE in NZ was conducted in 1994[17] and reported a prevalence of 73%. Today, this would represent nearly 230,000 surfers having the condition, a number more than two-fold higher than we found in this study. Chaplin and Stewart[17] reported that 92% of people surfing for more than 10 years had developed exostoses. The mean surfing experience of our cohort was 16.2 years, so we expected to find a higher prevalence than we actually observed. The discrepancy between the results of these two studies could be partially explained by the fact that most surfers in our study (86%) were from the North Island, with almost one-third from the Auckland region (mean water temperature of ~17°C),[13] whereas 92% of the participants investigated by Chaplin and Stewart[17] were from the South Island, with many probably local to the Otago area (mean water temperature of ~12°C).[13] A strong association between cold-water exposure and EAE has been reported in the literature.[5,27,29,30] However, the present investigation was unable to demonstrate this correlation, as there was a non-significant difference between highest and lowest quartiles for winter hours surfing exposure and exostoses. Chaplin and Stewart[17] noted that the seven surfers from the North Island had less severe exostoses than surfers from the South Island, despite a similar exposure of surfing in winter ($P < 0.005$) however, they did not report differences between islands in EAE prevalence. Similarly, in the present study, we found no difference in lifetime EAE prevalence between surfers who mainly surfed in the North versus South Islands and no difference in prevalence according to time spent surfing in winter months.

Another explanation for the difference in EAE prevalence noted here and previously could be related to the methods used to assess EAE. Chaplin and Stewart[17] examined participants via operating microscope by two assessors, who assessed the presence and severity of EAE. In our study, surfers answered a questionnaire where they were asked whether they had previously had EAE diagnosed by a doctor. An even larger disparity in the prevalence of EAE was noted in two Australian studies.[31,32] A study assessing self-reported surfing injuries, but not specifically questioning about EAE, found that only 3.5% reported having a surfing-related ear injury.[31] This is in contrast to another study,[32] where the condition was assessed by otoscopy and found a prevalence of 76%. The dissonance between self-reported and externally assessed prevalence may suggest low awareness of surfers about the condition, yielding concerns with respect to the condition being overlooked by health practitioners.

Previous research has established that exostoses are highly correlated with the amount of time spent in the water, with risk increasing after five sessions of surfing per month, and significantly increasing after 5 years of surfing.[10,11] We found that surfers in the highest quartile of surfing exposure had a two-fold increase in the prevalence of EAE. Consistent with the literature, we found that participants who reported surfing for >5 years had a higher prevalence of EAE than surfers who had surfed for < 5 years, having more than a seven-fold higher risk of developing the condition. Although the age of the youngest surfer to report having EAE in our study was aged 13 years, she had 8 years of surfing experience.

Traditionally, EAE is more commonly found bilaterally[1] and we also found that nearly 74% of the surfers with EAE had both ears affected by the condition, with no difference between left and right ears. This finding is also consistent with other research[17] reporting that statistically both ears were affected in the same proportion.

Two strengths of this study are the large sample size and the relatively high response rate that could be obtained from a survey strategy taking advantage of close networks among the New Zealand surfing community. These features are likely to reduce response bias, and allow for more accurate estimates of prevalence. Furthermore, we conducted a national survey, aiming to reach a representative spread of individuals throughout the country, which included recreational and competitive surfers. However, several limitations should be acknowledged. First, the prevalence of EAE was based on self-reported information and not on otologic examination, and therefore the prevalence reported here may be underestimated. Additionally, this design did not allow us to gather data on the severity of the condition. Almost all participants currently resided in NZ and had lived in the country for 6 of the previous 12 months. This population might therefore have included surfers who had previously lived in places where surf conditions, such as warm water, may be associated with a lower prevalence of exostoses. Past movement between regions may also explain lack of difference between those who currently mainly surf in the North and South Islands. Third, we did not include questions related to the use of protective equipment. Protective equipment is recommended by the American Academy of Family Physicians,[7] but Chaplin and Stewart[17] reported no difference in EAE prevalence between surfers who wore protective earplugs and those who did not. Finally, we did not account for participation in other water activities notwithstanding, the study by Chaplin and Stewart[17] reporting no significant difference between individuals who engaged in other water sports and those who did not.

The results of this study have shown that the prevalence of EAE, although lower than a previous study assessing NZ surfers in the southern region of the country, is likely to affect nearly 100,000 individuals in NZ. Moreover, we demonstrated that individuals surfing for >5 years have an increased risk of developing exostoses, and the lesions can start developing at an early age, as early as 13 years. There is, therefore, a need for awareness in general practice of EAE risk for individuals who surf, aiming at prevention, early treatment or appropriate referral for people with this condition. Further research should focus on assessing surfers via otologic examination, determining not only the prevalence but also severity of the condition.

Author Contributions

All authors declare that they have made a substantial contribution based upon guidelines developed by the International Committee of Medical Journal Editors (http://www.icmje.org/recommendations/browse/roles-and-responsibilities/defining-the-role-of-authors-and-contributors.html).

Competing Interests

The authors declare no competing interests.

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